TP 5611E

FEASIBILITY STUDY OF MECHANICAL ICE BREAK AND REMOVAL TECHNIQUES

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5670 Spring Garden Road
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July 1984

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FEASIBILITY STUDY OF MECHANICAL ICE BREAK AND REMOVAL TECHNIQUES

by

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July 1984

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

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REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 5611E	4962, 4963	

4. Title and Subtitle	5. Report Date
Feasibility Study of Mechanical Ice Break and Removal Techniques	July 1984
	6. Performing Organization Report No. L060

7. Author(s)	8. Transport Canada File No.
R.K. Watanabe and B.P. Garrett	D1460-201

9. Performing Organization Name and Address	10. DSS File No.
Martec Limited 5670 Spring Garden Road Halifax, Nova Scotia B3J 1H6	12SD.T8200-3-3505
	11. DSS or Transport Canada Contract No. 1SD83-00144

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Transportation Development Centre (TDC) 1000 Sherbrooke Street West Suite 2421 Montreal, Quebec H3A 2R3	Final; Jan. 84 - July 84
	14. Sponsoring Agency Code TDC 4962, 4963

15. Supplementary Notes	16. TDC Project Officer
	R.S. Nishizaki

17. Abstract

This report presents the results of a feasibility study of cutting ice cover into blocks and mechanically displacing the blocks as a technique for ice management in ports and harbours. Single-block tests to verify the technique and multi-block tests to demonstrate the effectiveness of clearing large areas are summarized. The measured forces and the estimated cost of the large-scale ice removal method are given. Further improvements to the equipment ("Ditch Witch" trencher and chainsaw) used in the full-scale tests are suggested and a sequential procedure for removing rough ice sections or ice near open water are also described. A projection is given for the cost of ice removal operation per unit area of open water created for harbours in southern Canada. The conclusion of the study is that the ice-block-under-ice technique is feasible as proven by demonstration. Cost is approximately $1.50 per square metre for landfast ice, with a small marginal increase in cost for rough ice. Cost of ice removal near open water is in the range of $0.08 to $0.30 depending on the amount of trenching. Further research is recommended at other locations including the Arctic.

18. Key Words	19. Distribution Statement
Ice Management, Ports and Harbours, Ice Cutting/Removal	Limited number of copies available from TDC

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	73	Nil

TDC/CDT 79-005

FORMULE DE DOCUMENTATION POUR RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP 5611E	4962, 4963	

4. Titre et sous-titre	5. Date du rapport
Feasibility Study of Mechanical Ice Break and Removal Techniques	July 1984
	6. N° du rapport de l'organisme exécutant: L060

7. Auteur(s)	8. N° de dossier Transports Canada
R.K. Watanabe et B.P. Garrett	D1460-201

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Martec Limitée 5670 Spring Garden Road Halifax, Nova Scotia B3J 1H6	12SD.T8200-3-3505
	11. N° de contrat — ASC ou Transports Canada: 1SD83-00144

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
Centre de développement des transports (CDT) 1000 ouest, rue Sherbrooke Suite 2421 Montréal, Québec H3A 2R3	Final; jan. 84 - juillet 84
	14. Code de l'organisme parrain: CDT 4962, 4963

15. Remarques additionnelles	16. Agent de projet — CDT
	R.S. Nishizaki

17. Résumé

Ce rapport présente les résultats d'une étude de faisabilité concernant une nouvelle méthode de déglaçage des bassins et rades portuaires, soit le découpage de la couverture de glace et l'enlèvement par des moyens mécaniques des blocs ainsi obtenus. Il décrit les essais de découpage d'un bloc unique visant à vérifier la technique envisagée, et ceux de découpage de plusieurs blocs à la fois afin de montrer l'utilité de la méthode pour le déglaçage de grandes surfaces. Il précise les forces à mettre en oeuvre pour l'enlèvement des glaces et donne le coût estimatif d'une opération touchant de grandes surfaces. Il suggère des perfectionnements à apporter aux matériels (trancheuse Ditch Witch et tronçonneuse) utilisées dans les essais de découpages multiples et décrit une procédure ordonnée pour l'enlèvement de la glace fixée bloquant les ports. Il propose des variantes dans le cas des glaces hummockées et pour le déglaçage des zones proches des eaux libres. Il fait une projection des coûts de déglaçage par unité de surface d'eau libérée des glaces, dans le cas des ports du sud du Canada. Le rapport conclut que la méthode dite "ice-block-under-ice" est techniquement faisable, comme il a par ailleurs été démontré. Le coût estimatif s'établit à 1,50 $ par mètre carré de glace fixée, avec un léger surcoût dans le cas des glaces hummockées. Le coût estimatif du déglaçage des zones proches des eaux libres s'établit entre 8 et 30 ¢, selon l'ampleur des travaux de découpage à faire. Enfin, ce rapport propose que la recherche soit étendue à d'autres emplacements, y compris l'Arctique.

18. Mots-clés	19. Diffusion
Gestion des glaces, ports et quais, découpage de la glace/dégagement	Nombre limité d'exemplaires disponibles au CDT

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
non-classifié	non-classifiée	aucun	aucun

Acknowledgements

The authors gratefully acknowledge the assistance provided by Earl Murray, Robert Hitchmen, Gary Grant, Douglas Geddes, Michael Askew, John Willette, Robert Hopkins, Vern Plummer and Kevin Plummer. The authors would also like to thank Master Warrant Officer Barry Ortman of the Department of National Defence for permission to conduct the ice tests at Anderson Lake, Nova Scotia, and Bruce Cameron for permission to perform the ice testing at Cameron's Beach, Ontario.

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ICE OPERATIONS AT CAMERON'S BEACH

1. INTRODUCTION

The need to clear ice away from piers without icebreaker assistance has motivated a feasibility study of the ice-block-under-ice technique proposed by Mr. Erik Banke, formerly the Arctic Group Manager of Martec Limited. The technique, which is limited to landfast ice, involves the cutting of ice into blocks. These blocks are subsequently tilted and towed underneath the surrounding ice leaving an area of open water in which a ship can maneuver.

This project complements the extensive ice management program which the Transportation Development Centre (TDC) has been engaged in for the Canadian Marine Transportation Association (CMTA) in Thunder Bay and for Canarctic Shipping in Little Cornwallis and Nanasivik. The National Harbours Board (NHB) is also very interested in these innovative techniques for ice management. Of particular interest is the potential to realize substantial energy savings over other techniques such as air bubblers.

To evaluate the feasibility of this method, three small scale tests were performed on successively thicker ice. A large scale test was then conducted to evaluate the various practical aspects of removing a series of ice blocks to create a large open water area.

The first interim report described the small scale tests of the ice-block-under-ice towing concept and presented a discussion of the preliminary results and operational aspects of the techniques. A second interim report was prepared following the large-scale tests. This final report summarizes the results of the field work and describes full-scale operational techniques for clearing ice from harbours to allow access of ships to piers when icebreaker assistance is not available.

2. SUMMARY OF RESULTS FROM FIELD WORK

2.1 Small Scale Tests

2.1.1 Description of Small Scale Test #1

The first test was conducted at Anderson Lake, Bedford, Nova Scotia, with an ice thickness of 30 cm. A block of ice 3x4 m was cut by making two parallel chainsaw cuts, 10 cm apart, around the perimeter of the ice block. The long pieces of ice that were formed were cut into 1 m long lengths and pushed underneath the surrounding ice using crowbars. This technique was also used to make a slot for the towing cable (see Figure 1a). The leading edge of the ice block was cut at an angle of approximately 45° so that the block would be forced to slide underneath the surrounding ice. A 15 cm diameter hole was drilled near the centre of the ice block and an ice anchor inserted.

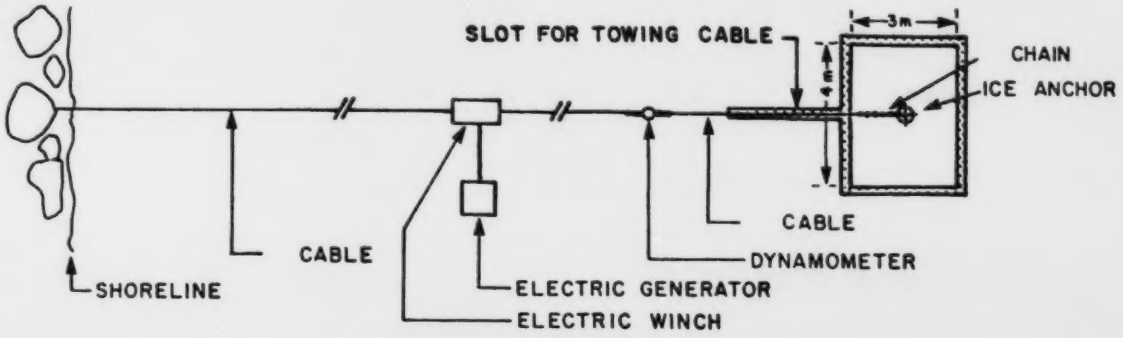
The ice anchor consisted of a length of chain wrapped around a wooden timber that was inserted lengthwise through the hole in the ice block. Once the timber was below the ice, the chain was pulled so that the timber rotated and lay flush against the lower ice surface. The other end of the chain was then attached to a dynamometer to measure tension on the cable. The dynamometer was then connected to another cable from an electric winch which was anchored to shore.

As the winch applied a force, the ice block submerged and slid under the surrounding ice in one quick motion (see Plate 1). A peak force during the entire operation of approximately 6,233 N (636 kg) was measured by the dynamometer. The block was returned to its original position by placing an additional ice anchor and pulley on the far side of the block and looping the towing cable around the pulley (see Figure 1 c and d).

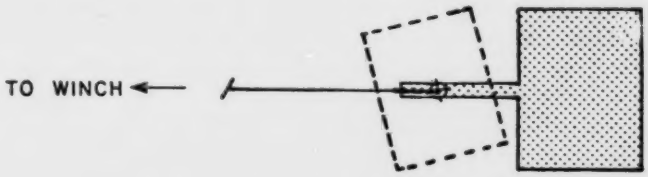
A larger 3 by 12 m block was then cut out using the same cutting technique used on the first block. Towing proved unsuccessful since the winch did not have sufficient pull to submerge the leading edge of this ice sheet. Testing was halted at this point while an attempt was made to obtain a more powerful winch and/or a device that would assist in the tilting of the ice block.

2.1.2 Discussion of Results

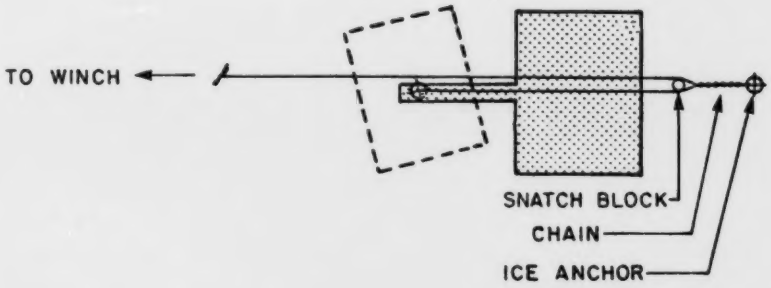
The chainsaws were found to be suitable tools for cutting the ice blocks and the slabs for the towing cable. However, they were difficult to start when cold and prone to stalling during cutting because of considerable spraying of water from the chain. The cold temperatures caused the water to freeze on contact with the motor and clothing which made working difficult. A guard would be constructed from



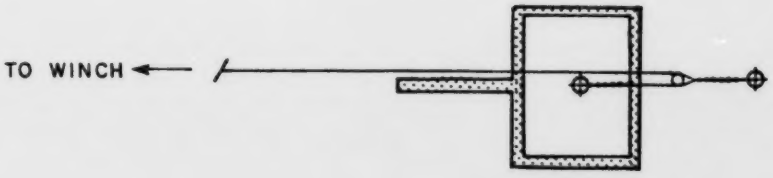
(A) TOWING ARRANGEMENT TO SUBMERGE BLOCK



(B) BLOCK TOWED UNDER SURROUNDING ICE



(C) TOWING ARRANGEMENT TO PULL BLOCK OUT FROM UNDER ICE



(D) BLOCK RETURNED TO ORIGINAL POSITION

FIGURE 1

INITIAL TEST ON 3X4 METRE BLOCK, ANDERSON LAKE , NOVA SCOTIA

plywood and attached to the chainsaw handle with hoseclamps to reduce the amount of spray near the chainsaw motor in future tests.

The crowbars were found to be effective tools for pushing ice chunks under the water, prying pieces of ice loose from the surrounding solid ice, breaking up ice chunks which became jammed, and lifting ice pieces out of the water. It was easier to submerge the ice chunks than to lift them out of the water. The jamming of the ice chucks was reduced by cutting the slots at an angle so that the piece of ice to be submerged was narrower at the top.

The ice anchors were considered to work well, although the removal of the anchors following each test required a member of the project team to reach into the water and manually pull the end of the anchor back through the hole in the ice. This method would not be suitable for thicker ice conditions, or for full scale operations where the ice block would be left under the surrounding ice and the anchor would be beneath two thicknesses of ice.

The use of a snatch block and ice anchor to reverse the towing direction seemed to work well and presented no practical difficulties. The dynamometer was considered to be a suitable force-measuring instrument for the tests. Although an additional scale pointer is provided to record the maximum reading, the towing force should be applied in a slow, steady motion, so that the readings can be monitored to prevent damage to the dynamometer if the full scale deflection of the instrument is exceeded. The variation in force at different stages of the operation can also be observed more easily if a slow pulling force is applied.

A standard shape of ice block for subsequent testing was deemed necessary to minimize the number of variables.

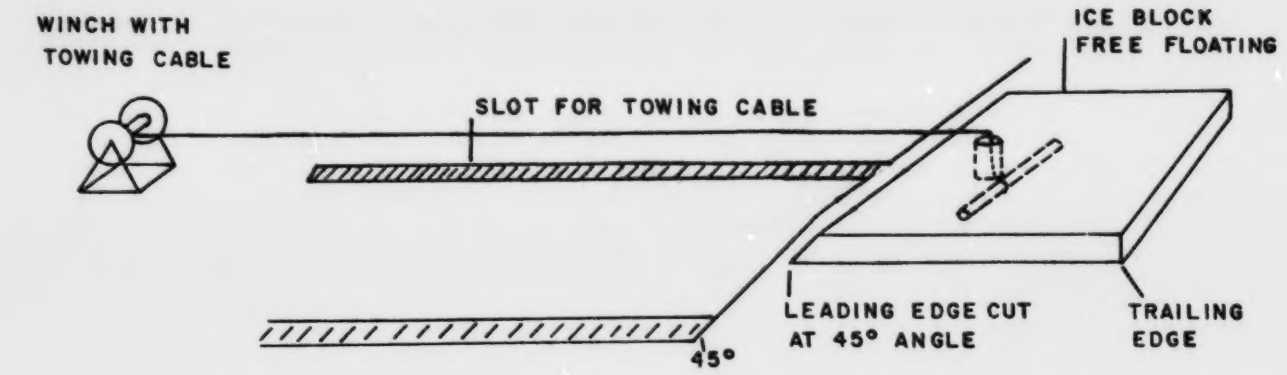
To minimize the torque required to tilt the ice block, the distance from the leading edge to the trailing edge of the ice block should be kept to a minimum. Other considerations include the strength and the ability of the ice block to resist twisting. A decision was made to maintain a length/width ratio of 4:5 for subsequent testing.

To aid in the tilting of the ice block, a tripod was constructed which would be placed on the ice block to support the towing cable above the level of the ice. The height of the tripod would increase the moment arm of the pulling force exerted by the winch so that the tilting of the ice block could be achieved with a smaller towing force (see Figure 2).

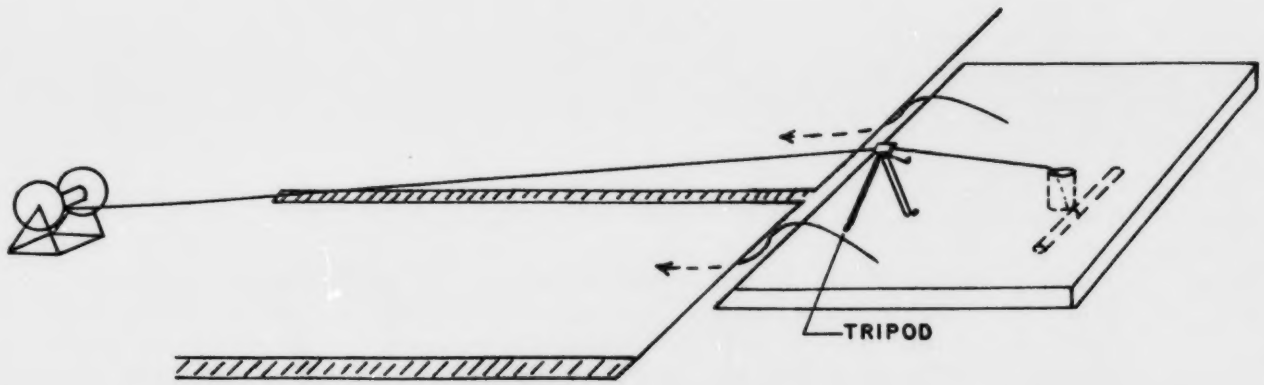
2.2 Small Scale Test #2

2.2.1 Description of Small Scale Test #2

A critical lack of adequate ice in Nova Scotia made it necessary to conduct the second test at French Lake near Fredericton, New Bruns-



STRAIGHT PULL



MOMENT ARM INCREASED
WITH USE OF TRIPOD

FIGURE 2

INFLUENCE OF TRIPOD ON THE TILTING OF ICE BLOCK

wick, where an ice thickness of 45 cm was reported. A backhoe was contracted to clear snow from an access road to the lake but unfortunately, the operator was reluctant to venture onto the ice with his machine. An area of the lake was cleared of snow by hand and two ice blocks measuring 4x5 m and 4.8x5.5 m were cut with the chainsaws.

The newly constructed 1.2 m high tripod was mounted 0.3 cm from the leading edge of the small block. The ice anchor was placed through a hole drilled 1 m from the trailing edge of the block. The electric winch was unable to apply sufficient force so a hydraulic hoe mechanism of the backhoe was used. Tension was applied and the leading edge of the ice block submerged under the surrounding ice at a force of 6,017 N (614 kg). Unfortunately, there was a sand bar at this location and the ice block jammed on the bottom with subsequent towing.

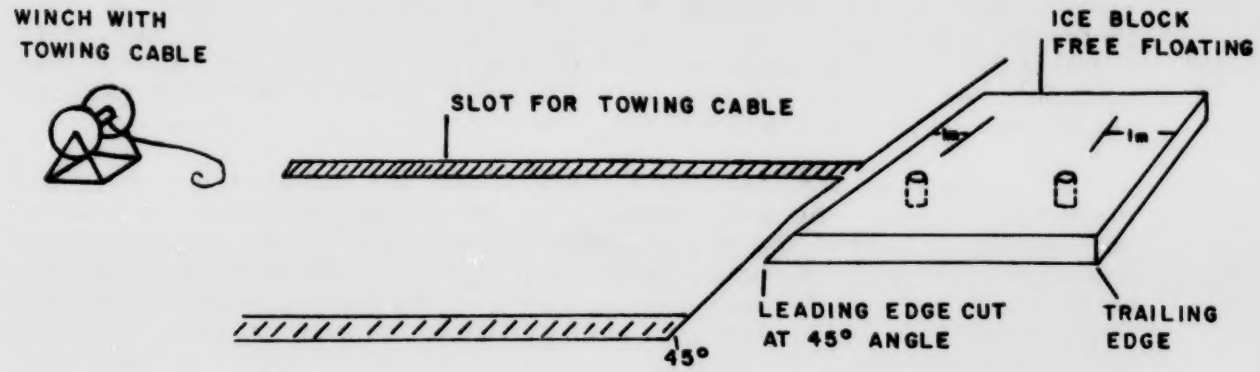
With the larger block, a variety of ice anchor/tripod arrangements were tested. The arrangement which minimized the tow force involved the placement of ice anchors about 1 m from the leading and trailing edges of the ice block. The tripod was installed 0.5 m from the leading edge of the ice block with the cable from the rear ice anchor placed ontop of the tripod. With this arrangement, a maximum force of 8,908 N (909 kg) was required to tilt the block and submerge the leading edge under the surrounding ice.

The next stage in the sequence was to move the tripod from the leading edge to a position near the centre of the ice block. It was anticipated that releasing tension on the towing cable at this point might cause the block to slip back and up into its original position, but sufficient friction between the two ice surfaces prevented any movement from occurring.

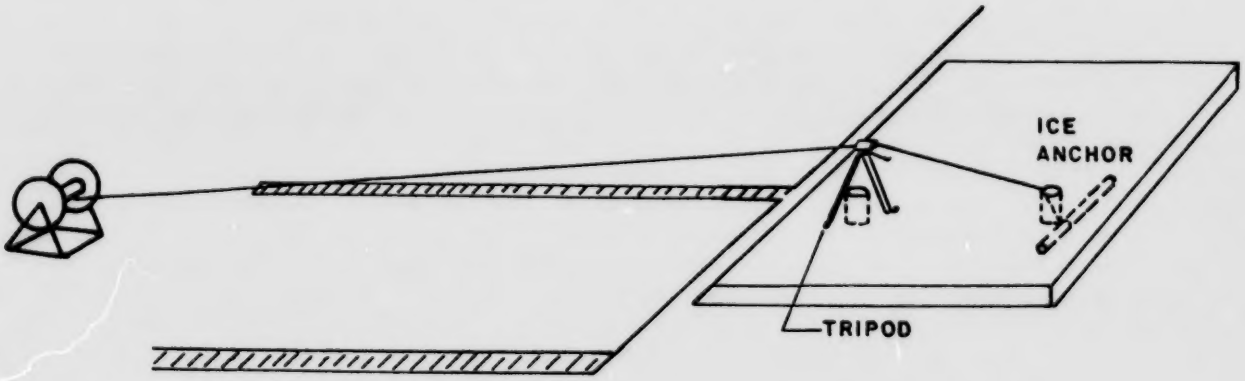
With the tripod centrally located on the ice block, tension was applied and at a dynamometer reading of 8,016 N (818 kg) the block slid so that it was halfway under the ice. Cable tension was removed again and the tripod and rear ice anchor were removed. The towing cable was connected to the front anchor and tension reapplied. A maximum force of 10,691 N (1,091 kg) was required to pull the ice block completely under the ice. The complete sequence is shown in Figure 3.

2.2.2 Discussion of Results

The ice anchors were modified slightly during this series of tests to facilitate the removal of the ice anchors in thick ice conditions. The anchors were initially removed by reaching into the water and pulling the end of the anchor through the hole. However, there were difficulties in reaching the anchor through the thicker ice and through two thicknesses of ice when the block was under the surrounding ice. A short length of rope was connected to one end of the ice anchor; the free end of the rope was secured to the chain on the anchor. The anchor was removed by pushing down on the anchor with a long crowbar (or lowering sufficient chain into the hole to sink the anchor), then pulling on the rope to lift the end of the anchor through the hole. This modification worked quite



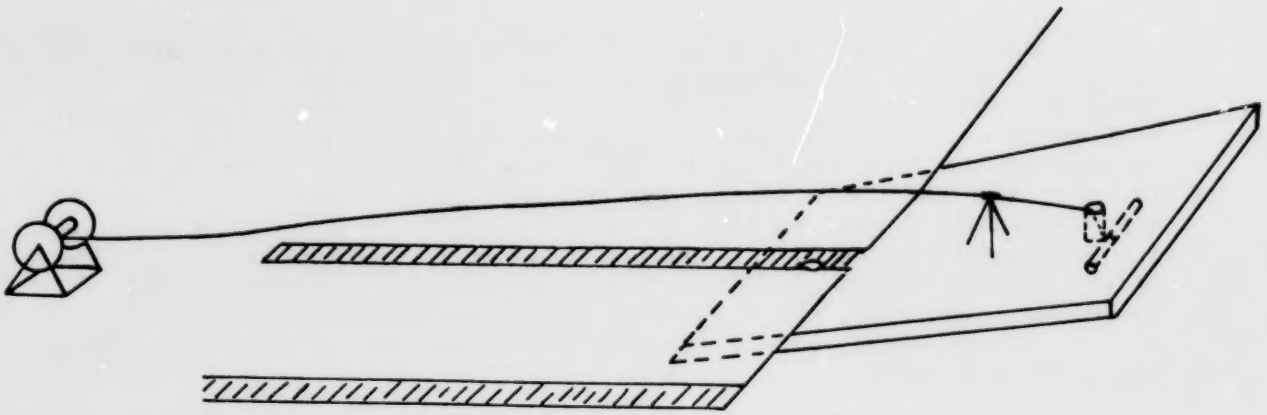
(1) ICE SHEET AND SLOT FOR CABLE CUT WITH THE USE OF CHAINSAWS



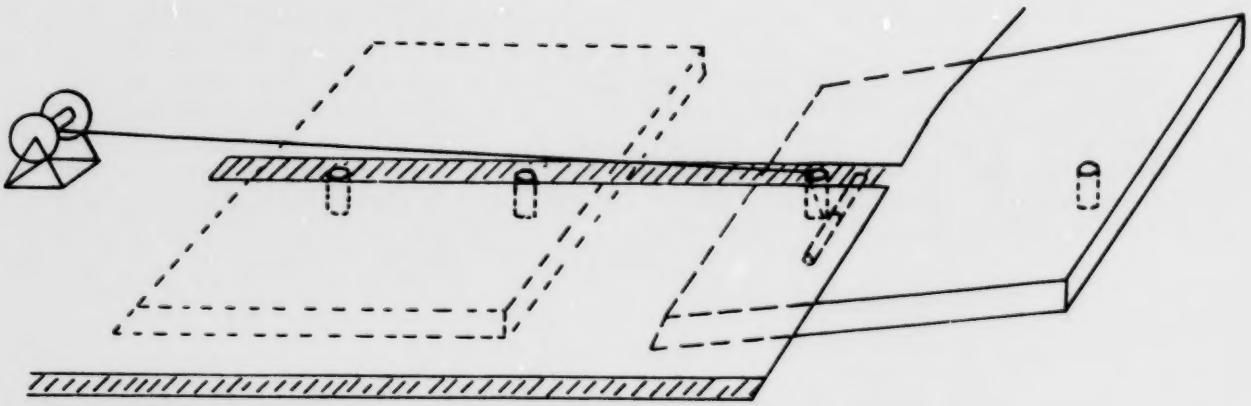
(2) INSERT ICE ANCHOR THROUGH REAR HOLE IN ICE BLOCK. PLACE FORWARD EDGE OF TRIPOD ABOUT 0.5 METRES FROM LEADING EDGE OF ICE BLOCK.
CONNECT TOWING CABLE TO REAR ICE ANCHOR AND PLACE CABLE OVER TOP OF TRIPOD

FIGURE 3

APPLICATION OF ICE-BLOCK-UNDER-ICE CONCEPT



(3) APPLY TENSION UNTIL LEADING EDGE OF ICE BLOCK SLIDES UNDER SURROUNDING ICE. RELEASE TENSION. MOVE TRIPOD TO MIDDLE OF BLOCK AND PULL BLOCK HALF WAY UNDER ICE.



(4) REMOVE TRIPOD AND REAR ICE ANCHOR.CONNECT TOWING CABLE TO FRONT ICE ANCHOR.PULL SHEET INTO ITS FINAL RESTING POSITION.
REMOVE ICE ANCHOR.

well and all of the ice anchors were later modified in this manner.

It was suggested that instead of cutting the ice with chainsaws, the power ice auger could be used if holes were drilled close together. This required careful positioning of the holes to prevent excessive overlapping and stoppage of the drill bit. The auger also deposited a large quantity of crushed ice and water around each hole, which had to be cleared in order to position the auger to drill the next hole. Once a line of holes was completed, it was necessary to use a chainsaw to smooth the edges of the overlapping holes or cut the ice between the individual holes. The entire process was much slower than the procedure developed with the chainsaws. However, the ice augers were convenient tools for installing the ice anchor holes, and for marking the corners of the block and towing slot prior to cutting with chainsaws.

A snowstorm during the testing hampered operations significantly but did not prevent the testing from continuing. Snow made access to the lake difficult as well as requiring frequent shovelling of the area around the ice block. The weight of the snow tended to decrease the general level of the ice surface relative to the water. As a result, the top surface of the snow cleared from the floating ice block was higher than the surrounding ice. The water flooded the surrounding ice near the block and produced difficult working conditions. In future tests, one of the requirements would be machinery capable of clearing the ice surface of snow.

Since we wanted to conduct the next test on thicker ice, it was decided to conduct the third small scale test at a location further north. The previous tests had been conducted using lake ice, however, it was expected that the difference in the amount of salts in fresh water ice and sea ice would affect the structure and strength of the ice cover. The buoyancy forces were also expected to be greater in salt water than in fresh water. The decision was made to conduct the third test using ice near Miramichi Bay, New Brunswick.

2.3 Small Scale Test #3

2.3.1 Description of Small Scale Test #3

The third series of tests was conducted at Gordon Point Wharf on the Miramichi River new Lower Newcastle, New Brunswick. Ice thickness at this location varied from 45 to 50 cm.

A backhoe operator was contracted to clear a path from the approach road to the ice surface and a large section of the ice surface. The removal of snow from a section of ice considerably larger than the test area caused the ice to flex upward (see Plate 2). This would prevent flooding once holes were created in the ice surface. Chainsaws were used to cut out a 6.0 by 7.5 m ice block and a slot for the towing cable. Ice anchors were installed 1 m from both the leading and trailing edges of the block. The tripod was placed near the centre of the ice block.

As was demonstrated in the previous tests, the maximum force results after the tripod has been removed. It was reasoned that instead of initially starting with the tripod at the leading edge and then moving it to the middle, once the ice block was tilted, it would speed up the entire operation if the tripod was installed near the centre of the ice block. Unfortunately, the dynamometer was not operating correctly and as a result there are few tension measurements for this test.

Tension was applied to the rear ice anchor which had a chain overtop of the tripod. The leading edge of the block submerged under the surrounding ice, exposing approximately 1 m of open water behind the trailing edge. However, at this point, the ice block broke into three pieces with one of the cracks passing through the hole for the ice anchor near the trailing edge (see Figure 4).

Two more ice blocks (Blocks B and C) were measured and marked on the ice adjacent to the previous block. Block B had dimensions of 5.5 by 8.875 m while Block C measured 5.0 by 6.26 m. Lines were marked on the ice, using yellow spray paint, to outline the blocks, the slots for the cable and the holes for the ice anchors. The paint worked well except in areas where the ice was wet where it would deteriorate relatively quickly.

The marking and cutting operations were timed and it was found that it took two people approximately 45 minutes to measure and paint all the lines and an hour to complete the cutting of the two blocks and the submerging of the long chunks of ice under the surrounding ice.

Block C was pulled directly towards shore using the same system of cables and chain used in the previous test. The tripod was placed on the leading edge and the block twisted in a clockwise direction as it was pulled from the ice anchor near the trailing edge. The tripod was moved back towards the trailing edge and the block continued to twist in the same direction. The backhoe was moved to the side and the block was pulled from an angle, however the block remained twisted. The tripod was then removed and the block was pulled only from the anchor on the leading edge. As the cable was pulled along the slot in the surrounding ice, the block straightened and slid completely under the ice.

Block C was left beneath the surrounding ice. The ice anchors were removed through the slot and installed on Block B. The cable was attached to Block B again with the tripod on the leading edge. The block was pulled by the backhoe and became wedged against a broken piece of Block A. A chainsaw was used to free the block by cutting a section of the ice from the broken piece. The tripod was moved back 0.5 m towards the trailing edge and the block tilted with the leading edge beneath the surrounding ice, leaving about 2 m of open water behind the block. The tripod was then placed near the centre of the ice sheet and the backhoe continued its pull. The block submerged, leaving open water over approximately half of the original area occupied by the block. However, two cracks were produced in the surrounding ice as shown in Figure 5. The ice above the submerged portion of the block was noticeably raised relative to the surrounding ice, due to the buoyancy of the submerged ice sheet.

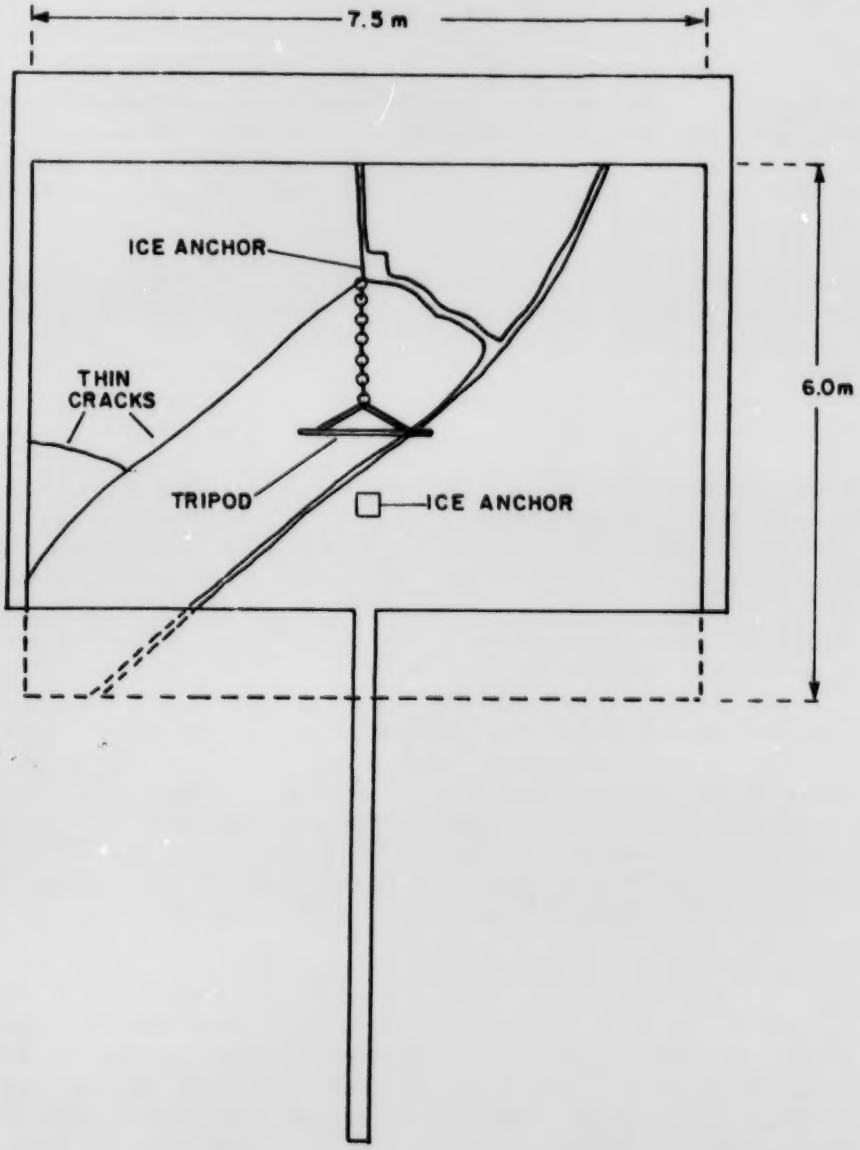


FIGURE 4

FRACTURE PATTERN
IN BLOCK A (6 BY 7.5m)
MIRAMICHI RIVER, NEW BRUNSWICK

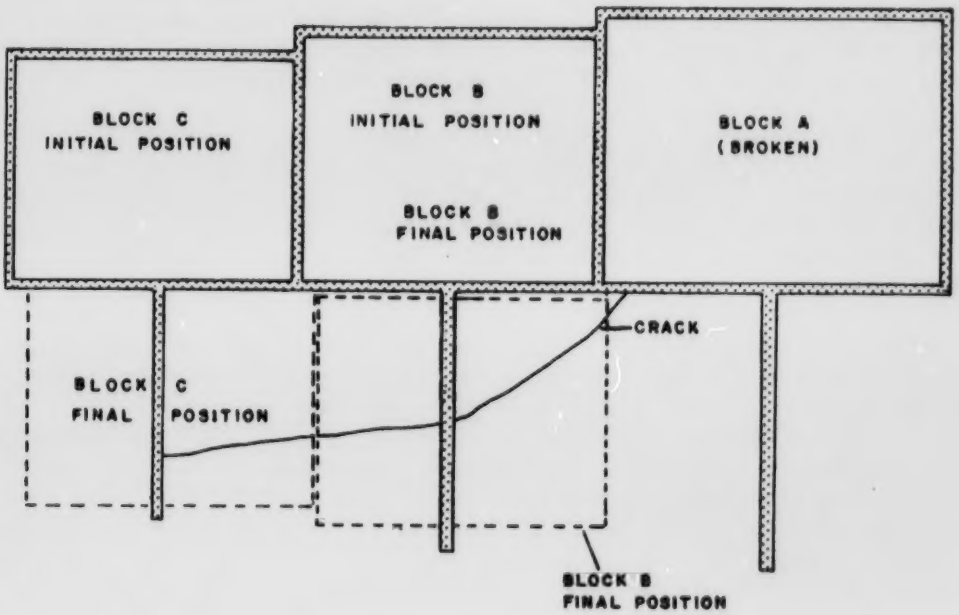


FIGURE 5

CRACKS IN ICE

MIRAMICHI RIVER, NEW BRUNSWICK

The tripod and rear ice anchor were removed and towing resumed from the front ice anchor. Block B slid completely under the surrounding ice and came to rest beside ice Block C, leaving an open area of water approximately 13 by 5 m in size (see Plate 3).

Both blocks were then pulled back into their original positions using the pulley system previously described. However, the cracked pieces on-top of the ice blocks remained there and were towed back with the ice blocks.

Three more ice blocks (D, E and F), were measured and marked on the ice as shown in Figure 6. Block D had the dimensions of 6.0 by 7.5 m, the same as that of Block A which broke. Blocks E and F had the dimensions 5.5 by 6.875 and 6.5 by 8.125, respectively.

With the dynamometer repaired, Block D was connected in a fashion similar to previous blocks. With the tripod placed near the leading edge, at a dynamometer reading of 31,181 N (3,181 kg) the block began to tilt, however, the leading edge did not fully submerge beneath the surrounding ice. The block was pried loose with the crowbars and returned to its original position.

When the ice block was originally cut, the angle on the leading edge and the surrounding ice was reduced from the 45° previously used to 15° from the vertical. This would determine whether this angle could be minimized in future tests. A force of 31,181 N (3,181 kg) was again applied but no movement resulted. A chainsaw was used to cut the edge of the ice to an angle of approximately 45° from the vertical but still the block refused to tilt significantly. The leading edge of the ice block was then cut at a 45° angle and at a reduced tow force of 26,727 N (2,727 kg) the ice block tilted and slid partway under the surrounding ice.

The tripod was moved to the middle of the block and movement resulted from a pull of 17,818 N (1,818 kg). A force of 20,491 N (2,091 kg) was required to slide the block to the point where it was halfway under the ice.

The tripod and rear ice anchor were disconnected and the towing cable attached to the front ice anchor. A maximum reading on the towline of 35,636 N (3,636 kg) was obtained, however, the block did not move away further under the ice. The test on this block was terminated at this point because the maximum capacity of the backhoe had been reached.

Blocks E and F were used to test another technique for submerging the ice blocks. The backhoe would use its hoe mechanism to submerge the ice blocks and then push them under the surrounding ice. While this technique may be limited since the hoe will not be able to maneuver the ice blocks once submerged under the ice, this may be a very effective technique for dealing with broken pieces of ice.

The backhoe pushed down on the leading edge of Block E and began to pull it under the surrounding ice (see Plate 4). The backhoe did not

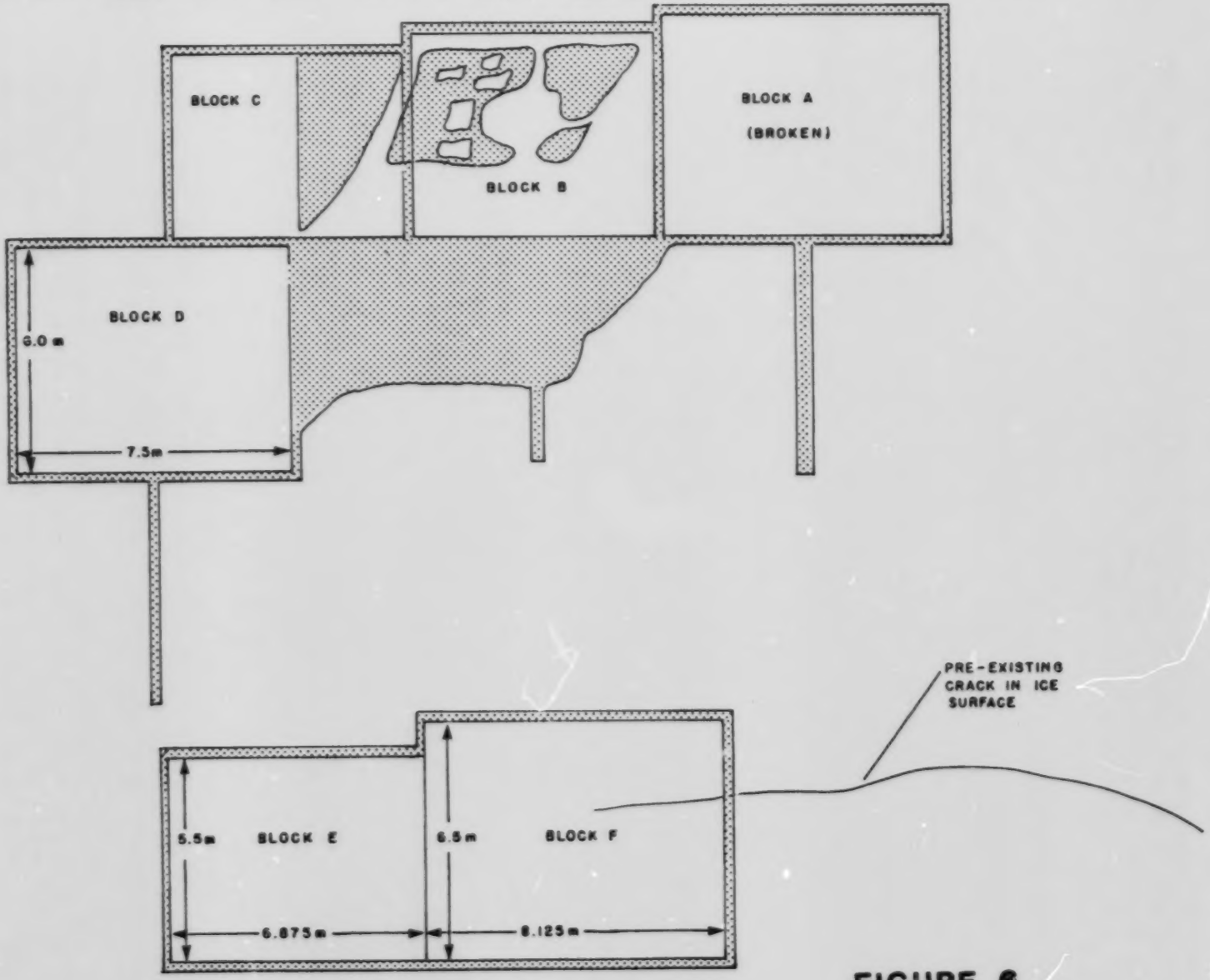


FIGURE 6

ORIENTATION OF BLOCKS D, E AND F
MIRAMICHI RIVER, NEW BRUNSWICK

have sufficient weight to submerge the entire ice block so the operator had to alternately move each corner further under the surrounding ice until the block was completely underneath the surface ice.

This technique was then applied to the larger Block F. However, as the backhoe pushed down on the leading edge, the ice block broke along a crack which was previously present on the ice. With the smaller pieces, the backhoe was able to completely submerge the ice chunks and push them under the surrounding ice quite effectively (see Plates 5 and 6).

2.3.2 Discussion of Results

The presence of snow was found to restrict access to the ice surface once again, but the use of a small backhoe on the ice was an effective solution. By clearing the snow from an area much larger than the actual testing area, the flooding of the ice surface due to the weight of the snow was prevented.

The ice consisted of two layers, with a soft layer of recently formed ice overlying a thicker, harder layer of older ice. It was suspected that cracks in the lower layer of ice may have been covered by the top layer of ice, and that Block A may have broken along these hidden fractures. Block D, which was the same size as Block A but further from the wharf, did not break when it was towed. The stronger ice anchors performed satisfactorily without breaking. However, the increased thickness of wood made it necessary to cut larger holes in the ice with chainsaws for installation of the ice anchors. These larger holes may have weakened the ice blocks. A decision was made to redesign the ice anchors using steel pipe and cable instead of wood and chain, for use in the future large scale tests.

The use of yellow spray paint was found to be useful for measuring and marking the dimensions of the ice blocks and maintaining the alignment of the chainsaw cuts. However, it was found that the paint tended to run and the lines deteriorated relatively quickly. A chalk bucket used to mark lines on football fields was purchased for use in the full scale tests.

Although the chainsaws were suitable for cutting the test blocks used in the small scale tests, they were considered to be too slow for use in the large scale application of the method. The decision was made to use a "Ditch Witch" to cut the trenches around the ice blocks in the future large scale tests. Due to the large areas of open water to be exposed in these tests, special tools will be fabricated for use in submerging small pieces of broken ice or maneuvering large blocks of ice through the water. The backhoe was found to be effective in sliding any large broken ice pieces underneath the surrounding ice, if difficulties are encountered with ice blocks breaking apart while being towed.

The tripod performed well except that the hinge mechanism became bent during the tests. The hinge would be strengthened and the top of the tripod would be modified to accommodate the steel cable of the new ice anchors. Because of frequent malfunction of the dynamometer, it was also

suggested that a dynamometer with a larger force range be used on the large scale tests.

The angle of the leading edge of the ice block was found to be an important factor in tilting the ice sheet. An angle of about 45° was considered to be a suitable value for the bevel on the leading edge. Maintaining an even bevel with the chainsaws was a difficult task but with experience, results became quite acceptable.

Placement of the tripod was also found to be an important consideration in the tilting procedure. Two procedures were developed, one in which the tripod was placed near the leading edge and then moved to the middle of the ice block once the leading edge was submerged and the other which involved the placement of the tripod initially near the centre of the ice block. The first procedure had the advantage that it stressed the ice block the least since the block was being pushed down at the front while being lifted up at the back. Tests had shown this method required slightly smaller towing forces. The second procedure, however, was faster since it did not involve moving the tripod during the tilting operation.

In certain cases, the static frictional forces between the leading edge of the ice sheet and the surrounding ice appeared to be considerably greater than usual, possibly because of adfreezing, or binding of ice chunks caught between the two ice surfaces. Imperfections in the angle and straightness of the chainsaw cuts may have also led to the same effect. When the ice block appeared to be jammed the most effective technique involved a pumping motion on the tow cable. The ice block would start to rock and then with a sudden continual pull at the right moment the ice block would slide completely underneath the surrounding ice. Throughout the remainder of the report, situations in which the ice block requires greater tow forces than would otherwise be suspected, will be referred to as a jammed ice block.

Although the medium sized blocks could be easily pried loose manually, the larger blocks presented difficulties. It was suggested that the maximum size of the ice block may be limited by the maximum force which the towing equipment can exert to free the block once it becomes "jammed". The use of slightly smaller blocks may be more efficient on a large scale, since the blocks will be more manageable and less time may be wasted in attempting to free blocks.

In the future large scale tests, a machine with a sufficiently large winch should be used so that ice strength, rather than winching capacity, becomes the factor that determines the maximum size block towed.

A summary of the dimensions, ice thicknesses, volumes and weights of the blocks tested is presented in Table 1. The force measurements for the small scale tests are summarized in Table 2 and plotted in Figure 7 for various stages in the towing operation. The forces required to begin tilting the ice block when the block is not jammed against the surrounding ice are plotted as a function of the volume of the block to indicate the

TABLE 1

SUMMARY OF ICE BLOCKS TESTED IN SMALL SCALE TESTS

Test Series	Location	Block Dimensions (m)	Ice Thickness (m)	Block Volume (cu.m)	Block Weight (kg)	Block Weight (lb)
1	Anderson Lake, N.S.	3 by 4	0.30	3.6	3,314	7,292
		3 by 12	0.30	10.8	9,943	21,875
2	French Lake, N.B.	4 by 5	0.43	8.6	7,918	17,419
		4.8 by 5.5	0.43	11.4	10,452	22,994
3	Miramichi River, N.B.	5 by 6.25 (Block C)	0.48	15.0	13,810	30,383
		5.5 by 6.875 (Blocks B and E)	0.48	18.2	16,710	36,763
		6 by 7.5 (Blocks A and D)	0.48	21.6	19,887	43,751
		6.5 by 8.125 (Block F)	0.48	25.4	23,339	51,347

TABLE 2

SUMMARY OF FORCE MEASUREMENTS FOR SMALL SCALE TESTS
(LE = Leading edge; TE = Trailing edge; M = Middle of block)

Test Series	Date	Block	Towing Equipment	Force (kg)	Force (lb)	Plot Point	Ice Anchors	Tripod Position	Block Motion	Comments
1	Fri., Feb. 10	3 by 4 m	Winch	636	1,400	A	M	Not used	Tilted and slid under ice	Maximum for entire operation
1	Fri., Feb. 10	3 by 12 m	Winch	-	-	-	M	Not used	Jammed	No movement
2	Tues., Mar. 13	4 by 5 m	Winch	614	1,350	B	TE	LE	Tilted below ice	
			Winch	909	2,000		TE	LE	Jammed	No movement
2	Weds., Mar. 14	4.8 by 5.5 m	Winch	614	1,350		LE, TE	LE	Tilted, then jammed	Pryed loose and slid under ice
				-	-		LE, TE	M	Tilted and slid under ice further	Removed tripod
				-	-		LE, TE	-	Jammed	No movement
2	Thurs., Mar. 15	4.8 by 5.5 m	Backhoe	409	900		LE, TE	LE	Tilted	Started again with slow pull
				909	2,000	C	LE, TE	LE	Tilted	Water level covering half of block
				1,136	2,500		LE, TE	LE	Jammed	Pryed loose
				1,136	2,500		LE, TE	LE	Tilted below ice	

TABLE 2 (Continued)

SUMMARY OF FORCE MEASUREMENTS FOR SMALL SCALE TESTS
(LE = Leading edge; TE = Trailing edge; M = Middle of block)

Test Series	Date	Block	Towing Equipment	Force (kg)	Force (lb)	Plot Point	Ice Anchors	Tripod Position	Block Motion	Comments
2 Cont'd	Thurs., Mar. 15 Cont'd	4.8 by 5.5 m (Cont'd)	Backhoe (Cont'd)	1,136	2,500		LE, TE	LE	Tilted further	Water level covering 3/4 of ice; tripod removed
				682	1,500		LE, TE	-	Slid under ice	1 m open water
				1,136	2,500		LE, TE	-	Jammed	No movement; disconnected LE ice anchor
				1,136	2,500		TE	-	Slid further	Half of block under ice
				1,250	2,750	E	LE	-	Slid further	2/3 of block under ice; jammed and pryed loose
				1,136	2,500		LE	-	Jammed	Pryed loose
				1,136	2,500		LE	-	Jammed	Changed dynamometer connection
				2,045	4,500	F	LE	-	Jammed	Rope broke; started again
				909	2,000	D	LE, TE	LE	Tilted and slid under ice	1/2 m open water
				818	1,800		LE, TE	M	Slid further	1 m open water
				818	1,800		LE, TE	M	Slid further	Water level covering half of block

TABLE 2 (Continued)

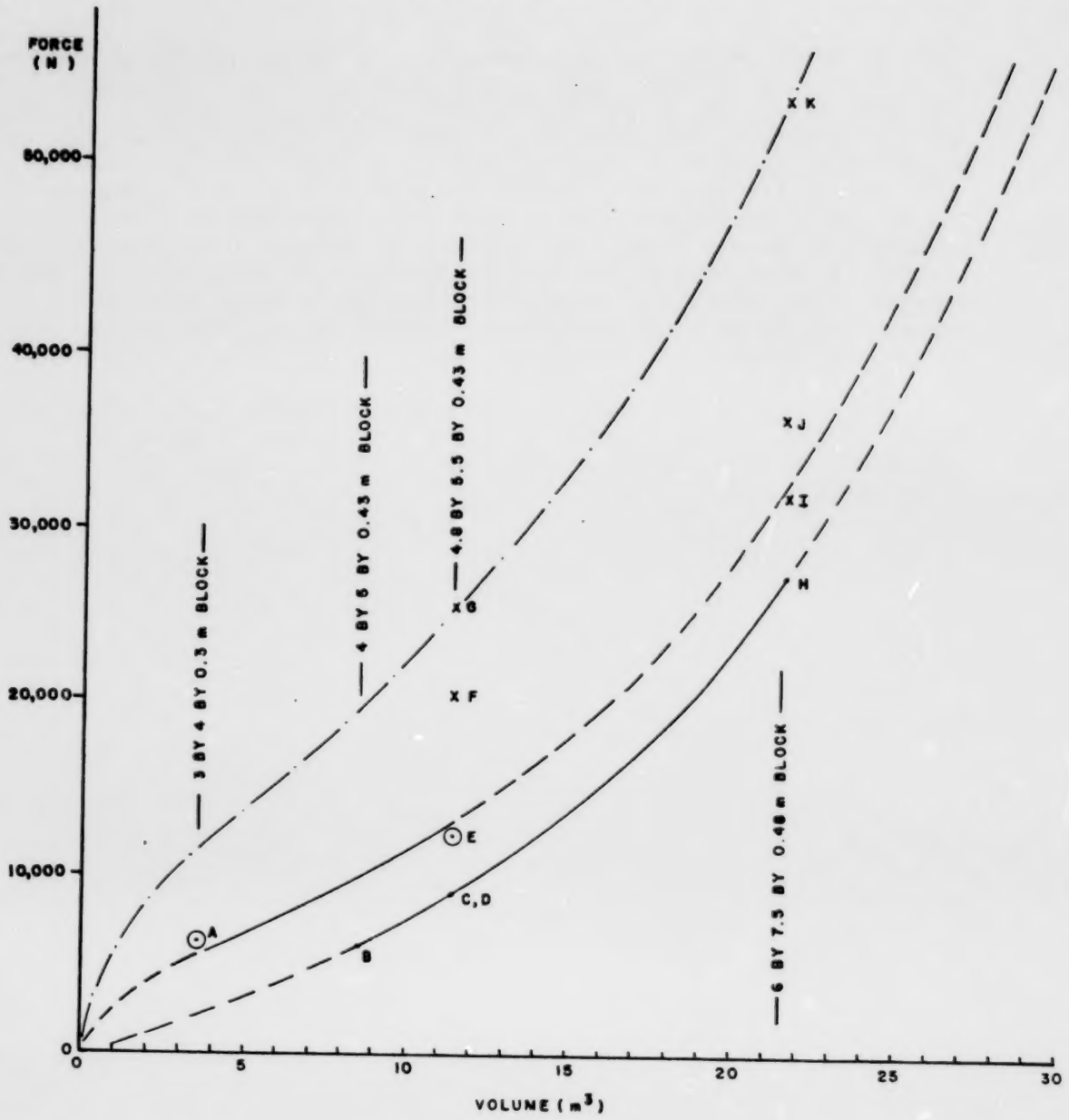
SUMMARY OF FORCE MEASUREMENTS FOR SMALL SCALE TESTS
(LE = Leading edge; TE = Trailing edge; M = Middle of block)

Test Series	Date	Block	Towing Equipment	Force (kg)	Force (lb)	Plot Point	Ice Anchors	Tripod Position	Block Motion	Comments
2 Cont'd	Thurs., Mar. 15 Cont'd	4.8 by 5.5 m (Cont'd)	Backhoe (Cont'd)	2,545	5,600	G	LE, TE	M	Jammed	Ice anchor broke; tripod removed and anchor replaced
				1,091	2,400		LE	-	Slid completely under ice	Started to pull block back to original position
				909	2,000		TE	-	Moved	
				1,136	2,500		TE	-	Pulled out from under ice	Returned to original position, but twisted
3	Weds., Mar. 21	6 by 7.5 m (Block A)	Backhoe	Dynamometer Not Operating						
3	Thurs., Mar. 22	5 by 6.25 m (Block C)	Backhoe	Dynamometer Not Operating						
		5.5 by 6.875 m (Block B)	Backhoe	Dynamometer Not Operating						
3	Fri., Mar. 23	5.5 by 6.875 m (Block E)	-	Backhoe Pushed Blocks Under Ice						
		6.5 by 8.125 m (Block F)	-	Backhoe Pushed Blocks Under Ice						

TABLE 2 (Continued)

SUMMARY OF FORCE MEASUREMENTS FOR SMALL SCALE TESTS
(LE = Leading edge; TE = Trailing edge; M = Middle of block)

Test Series	Date	Block	Towing Equipment	Force (kg)	Force (lb)	Plot Point	Ice Anchors	Tripod Position	Block Motion	Comments
3 Cont'd	Fri., Mar. 23 Cont'd	6 by 7.5 m (Block D)	Backhoe	2,727	6,000		TE	LE	Jammed	15° angle on LE and surrounding ice; pryed loose
				3,182	7,000		TE	LE	Began to tilt, then jammed	Pryed loose and started again
				3,182	7,000		TE	LE	Jammed	Pryed loose and started again cut 45° angle on surrounding ice
				5,455	12,000	K	TE	LE	Jammed	Pulled with pumping action, but no movement cut 45° angle on LE and started again
				2,727	6,000	H	TE	LE	Tilted and slid under ice	Block twisted
				1,818	4,000		TE	M	Slid further	Block still twisted
				2,091	4,600		TE	M	Slid further	Tripod removed
				3,182	7,000	I	LE	-	Jammed	
				1,909	4,200		LE	-	Jammed	Pull with chain on 1 hook of front bucket
				3,636	8,000	J	LE	-	Jammed	Pull with chain wrapped around front bucket



LEGEND

X- LARGEST FORCES WHEN BLOCK IS JAMMED AGAINST SURROUNDING ICE

⊙- MAXIMUM FORCE DURING ENTIRE OPERATION WITHOUT JAMMING OF ICE BLOCK

• - MINIMUM FORCE FOR INITIAL TILTING OF ICE BLOCK WITHOUT JAMMING

——— - ESTIMATED CURVE

– – – – - EXTRAPOLATED CURVE

—·— — - TREND OF FORCES WHEN BLOCK IS JAMMED

FIGURE 7

MEASURED FORCES AS A FUNCTION OF ICE BLOCK VOLUME FOR SMALL SCALE TESTS

minimum forces which may be necessary. The points plotted on the graph are identified by a letter code in the summary table. The largest forces observed during the entire towing operation are also plotted on the graph for the cases when the block is not jammed against the surrounding ice to suggest the maximum forces required. The data points are used to produce curves for estimating forces for other block sizes. The estimated curves are shown as solid lines, while the extrapolation of these curves re indicated as dashed lines. The dramatic increase in force when the block becomes jammed against the surrounding ice is illustrated by plotting selected data points for some of the largest forces observed in these cases. A dashed line was drawn through the largest forces only to suggest the general trend of these values.

The towing of ice blocks under the surrounding ice has been shown to be feasible on a small scale to expose a small area of open water. The application of the technique to clear ice from a large area was then investigated.

3. LARGE SCALE TESTS

The previous small scale tests of this concept demonstrated that this method was feasible on a small scale and appeared to be a promising technique for large scale applications. The large scale tests were intended to demonstrate the feasibility of the ice-block-under-ice concept for removing ice to create large open water areas and to debug the various operational aspects of the method.

When the availability of ditch cutting machinery was investigated, it was discovered that this type of equipment was generally not found in the Maritime Provinces. Although a "Ditch Witch" was sold to a resident of Minas, Nova Scotia, this machine was larger than the R40 Model being considered for use in the large scale tests. A more suitable size of Ditch Witch was available in Ontario and a comparison of transportation costs and transit time resulted in a decision to carry out the large scale tests in Ontario.

A telephone survey was then conducted to locate an area with suitable ice conditions and accessibility to the heavy equipment needed for towing purposes. The town of Midland was originally selected as the site of the large scale tests, since a grain elevator and government wharf in this area had not yet been freed from ice by the Coast Guard icebreakers. Arrangements were made to rent a Ditch Witch in the nearby town of Woodbridge and the chainsaws, ice augers, steel cable, chains and other equipment were shipped to Toronto.

A member of the project team travelled to Ontario to carry out a site survey of local ice conditions, rent heavy equipment and hire additional field personnel prior to the start of the testing. At this time, it was found that several days of mild weather had weakened the ice near the southern shore of Georgian Bay, so that this site was no longer suitable for conducting the large scale tests. Since the equipment had already been shipped to Ontario and arrangements had been made for rental of the Ditch Witch, an alternate site near North Bay was considered for the testing. Subsequent warm weather during the mobilization of equipment made this site unsuitable as well. Numerous sites around Timmins, Ontario were investigated and Cameron's Beach, located on Big Nellie Lake near the town of Iroquois Falls was finally selected for the testing.

3.1 Equipment

Prior to beginning the large scale tests, it was necessary to strengthen the design of the ice anchors and modify the tripod for use with steel cable instead of chain. Various tools and equipment which were not commercially available were designed and fabricated especially for use in the large scale testing. A snowmobile was also rented and a make shift sled was constructed from one of the packing crates to

speed up the transfer of equipment between the truck and the test area.

During the small scale tests, the metal plate and hinge bolt on the tripod were bent because the steel chain from the ice anchors often rested on the edge of the plate at this location. Since the new design of the ice anchors used cable instead of steel chain, it was suspected that the slot cut in the angle iron on the plate could possibly damage or cut the cable. The tripod was modified by cutting the metal plate slightly in front of the angle iron. This piece was then welded back on at a downward angle so that the cable would not rub at this point. The top plate was strengthened and a larger hinge mechanism was installed on the rear leg. A short piece of pipe with a wide slot through one side was then welded to the top of the tripod to accommodate the cable. The modified tripod is shown in Plates 7 and 8 (See Appendix B).

Wooden ice anchors which were used in the previous tests were not considered suitable. Progressively larger pieces of wood were required as the forces increased through the three preliminary tests. The larger pieces of wood required larger holes through the ice which led to significant weakening of the ice sheet. Although wood has the advantage that it floats and stays in place before tension is applied to the cable, it was decided to use steel pipe instead for strength considerations.

Wire rope slings were assembled in Halifax using 1.59 cm cable. A large loop was placed at one end to fit around the steel pipe and a hook was placed at the other end to attach to the towing cable (See Plate 9). In Ontario, 7.62 cm thick walled steel pipes, 1.2 m long, were inserted through the loop in the cable. Semi-circular steel rings were then welded onto the pipe, to hold the cable in the middle of the pipe. The steel rings were welded at a 45° angle to allow for a minimum of cable bending when the ice anchor was deployed or retrieved through the ice. A rope was attached to one of these rings and secured above the ice after the anchor had been deployed, to maintain proper alignment of the pipe to the ice sheet. This rope also acted as a safety line before the ice anchor was attached to the towing cable. A third steel ring was welded at one end of the steel pipe. A rope was tied here and the free end was secured above the ice. Retrieval of the ice anchor was accomplished by slackening off the cable and pulling on this rope, which would align the pipe vertically, allowing for removal. The system worked well but it was found that in some instances when the ice block came to rest under the surrounding ice, the hole would not be in exact alignment with the slot cut to accommodate the cable. This often required the chipping or cutting of the ice immediately above the hole to allow for retrieval of the ice anchor. A guide was required to keep the hole in the ice sheet aligned with the slot.

At first a wooden timber was installed vertically in the hole of the ice sheet. The timber would travel up the slot as the ice sheet

was pulled along. The timber worked well, but it broke off several times if too much ice and slush collected in the slot in front of it, or if the block being towed hit a stationary block beside it.

A steel guide was then constructed out of 12.7 cm tubing. The lower end was tapered to permit easy insertion into the hole. A steel bar was inserted perpendicular to the pipe's axis and welded about 0.5 metres from the bottom. This bar rested on the ice sheet and held the assembly from falling through the hole. The guide would be inserted as the ice block was travelling up the slot, but alignment of the hole and slot was necessary.

Often the block would slide to one side and the guide could not be inserted. This problem was overcome by tapering the entrance of the slot and inserting the guide as soon as the leading edge of the block was submerged and the tripod removed. This speeded up the entire procedure considerably and worked well for the remainder of the test.

The small scale tests showed that pry bars were invaluable for a variety of tasks. The one metre long construction type wrecking bar had proved useful but something much bigger and of a different design was needed. Three pry bars varying in length from 3 to 4 metres were fabricated using 3.8 cm square steel tubing for the shafts (See Plate 10). Segments of truck leaf springs were fitted into the ends of the shaft and welded, producing a wide flat prying surface (See Plate 11). The pry bars were extremely useful for freeing jammed pieces of ice as well as the chipping and breaking of ice.

A problem unique to the full scale test was that of moving and positioning the ice block for towing. Pike poles using hemlock shafts 4.25 metres long were designed to incorporate 3 steel prongs (See Plate 12). One prong was curved back toward the handle while the other two had a slight curve outward and were used for pushing.

The two tips were separated by 20 cm to add stability when submerging small pieces of ice as was done frequently in the previous tests. When maneuvering the large blocks, the two prongs would straddle the corner of the ice sheet and would therefore not rely exclusively on the sharp ends digging into the ice for traction. Of course, the blocks can only be positioned if they are within reach of the pike poles, and this was not always the case with a large open water area. A simple hook (See Plate 13) that could be put through the hole in the ice sheet was constructed. By standing on solid ice and pulling on the rope attached to this hook, one was able to maneuver the blocks quite suitably. It was anticipated that once the block was moved into position for towing, a means of holding it there would be needed. Steel stakes (See Plate 13) were made so that they would be driven into the solid ice. The rope to the ice block could then be tied tightly, holding the block in position for towing.

As work progressed rather quickly the need to hold each block ready for towing was not required. However, it was found that a method to move a large number of blocks into position quickly was needed. The method that proved most effective was to cut an entire row of blocks and slide them across as a unit until they were aligned with the cable slot. With the hook attached to the furthest block in the row, a steady force could be applied that would keep the blocks aligned and ready for towing. When a block was towed under the ice the remaining blocks could be moved as a unit towards the slot. This procedure generally worked well except during windy conditions.

3.2 Description of Large Scale Testing

3.2.1 Marking, Cutting and Maneuvering Techniques

Although the weather had been clear during the search for a test site, a snowfall of 10 cm occurred on Friday, April 6, which was the first day of the ice testing operations. The equipment was unloaded from the truck and the small blade on the front end of the Ditch Witch was used to clear a path through the snow to the lake (See Plate 14). A 10.2 cm ice auger was used to drill test holes at various locations in the ice surface near Cameron's Beach. The ice thickness was found to vary from 60 to 75 cm depending on location. Although the ice at the shoreline was completely solid to the bottom of the lake, the water depth increased rapidly a short distance from shore.

Based on the available ice surface and water depths, the decision was made to remove ice from an area 45.7 m wide at a distance of 61.0 m from the shoreline. Wooden stakes were installed in a straight line at these distances from shore as shown in Figure 8. The ice removal operations began on the west side of the lake near the small island and extended eastwards to the point of land on the opposite side of the lake. The south edge was made perpendicular to the west edge by measuring a distance of 61.0 m across the lake, then using the diagonal measurement of 76.2 m (based on a 3-4-5 right angle triangle) to adjust the position of the stake to obtain the correct diagonal distance. This line was then extended to a distance of 152.4 m using a visual alignment of the markers. This procedure was repeated for the north edge of the test area.

Once the 152.4 by 45.7 m test area was marked with a wooden stake in each corner, an additional stake was placed at the midpoint of the side furthest from shore as a visual reference point. A line of stakes was installed across the lake and a warning sign was included to warn the general public about the ice testing. The stakes were sprayed with fluorescent paint and an additional stake was installed at the end of the test area furthest from Cameron's Beach.

The blade on the front end of the Ditch Witch was used to clear the snow from an area on the west end of the test area. The corner stakes were used as visual reference points and the cutting boom of

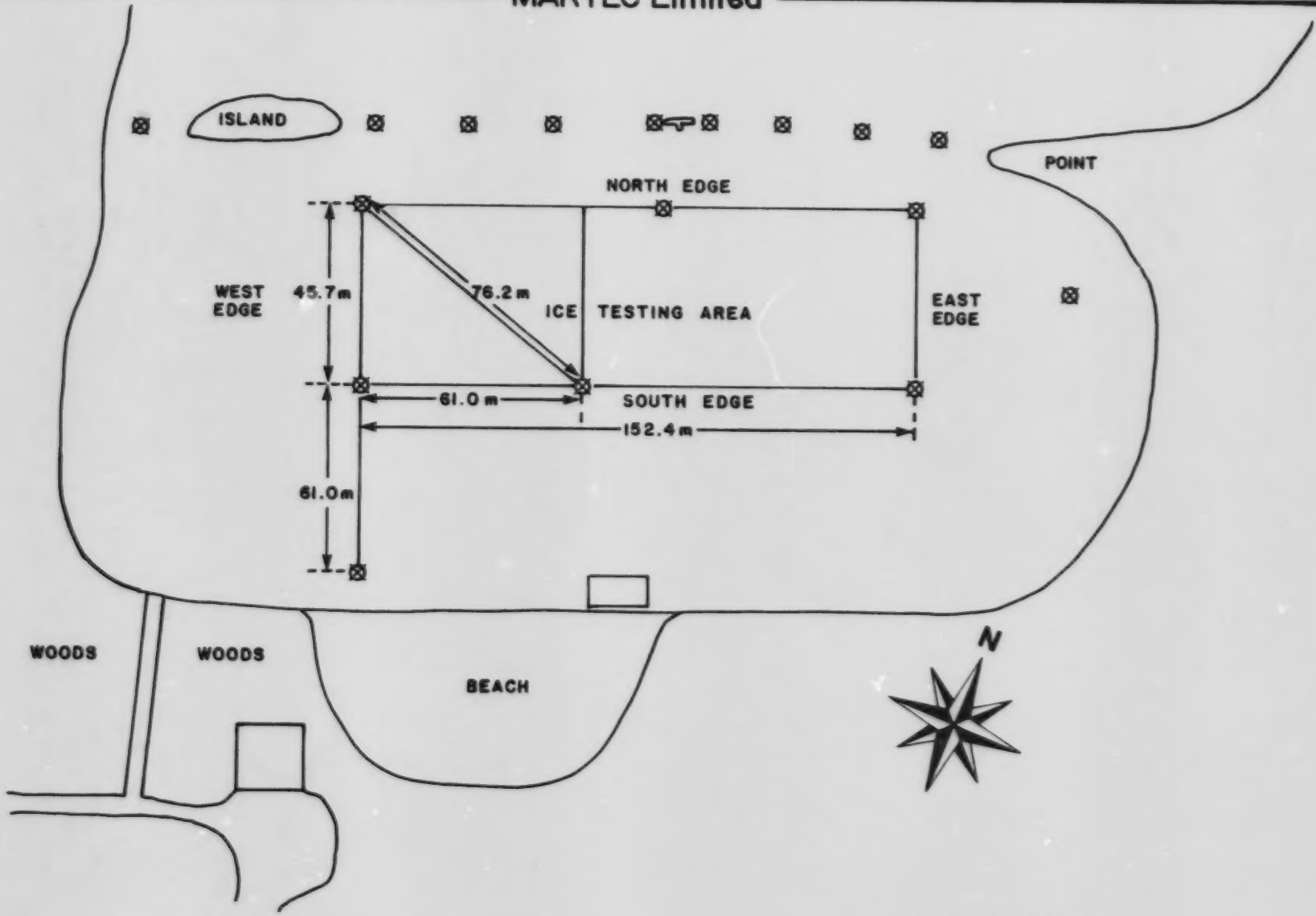


FIGURE 8

DIMENSIONS OF ICE-TESTING AREA

the Ditch Witch was dragged along the ice to mark the west edge of the first row of ice blocks (See Figure 9).

A distance equal to the width of the ice block (initially 6.125 m) was measured along the north and south edges of the test area and stakes were placed on the ice at these points. The Ditch Witch was then used to mark the east edge of the first row of ice blocks. The centerline of the row of ice blocks was marked with stakes and the slot for the towing cable was marked on the ice using the Ditch Witch.

The south edge of the first row of blocks was marked by dragging a steel pike pole along the ice using the stakes as visual reference points. Intervals equal to the length of the ice block (initially 5.0 m) were measured along the west and east edges of the first row of ice blocks and marked on the ice using a pike pole.

The measurement and marking procedures described above were later repeated for subsequent rows of ice blocks. Since the edges of the test area were previously aligned and marked with stakes, the measuring and marking of the individual ice blocks proceeded rapidly. The initial rows of ice blocks were 5.0 by 6.125 m in size, but a row of larger blocks 5.0 by 7.125 m was also tested. Although the towing equipment was adequate for these larger blocks, it was observed that the larger blocks tended to break into pieces more easily. The subsequent rows of ice blocks were then made 5.0 by 6.125 m in size. The Ditch Witch was used to cut the trenches for the west and east edges of the ice blocks and the towing cable slot, while chainsaws were used to cut the south and north edges of the ice blocks, as described in the following section.

On the first day of the ice testing, the Ditch Witch was used to begin cutting the west edge of the first row of ice blocks, but the ice cutting operation was found to be very slow. It has been reported that the S.G. Phillips Corp. in Williston, Vermont has used an R65 Model Ditch Witch to cut a trench through nearly three feet of ice at an average speed of about 122 m/hr (1). However, the rate of cutting measured for the R40 Model Ditch Witch was only 44 m/hr. The cutting teeth and chain brought a constant stream of water to the top of the ice and the rubber tires did not have sufficient traction to pull the cutting blade through the ice. The Ditch Witch frequently slid rapidly backwards as individual cutting teeth hit the lower edge of the ice surface but did not cut through the ice.

The rental company was contacted, and it was learned that a set of tire chains for the Ditch Witch is not commercially available. Some steel cable was wrapped around the front tires of the Ditch Witch and fastened with cable clamps and the large steel chain was placed on the front end post of the Ditch Witch to provide additional weight. Although the front tires had more traction, the back tires continued to slide backward or sideways on the ice. At times, the Ditch Witch did not move forward and the cables on each front tire began to scrape a small hole in the top of the ice. By the end of the first day, a

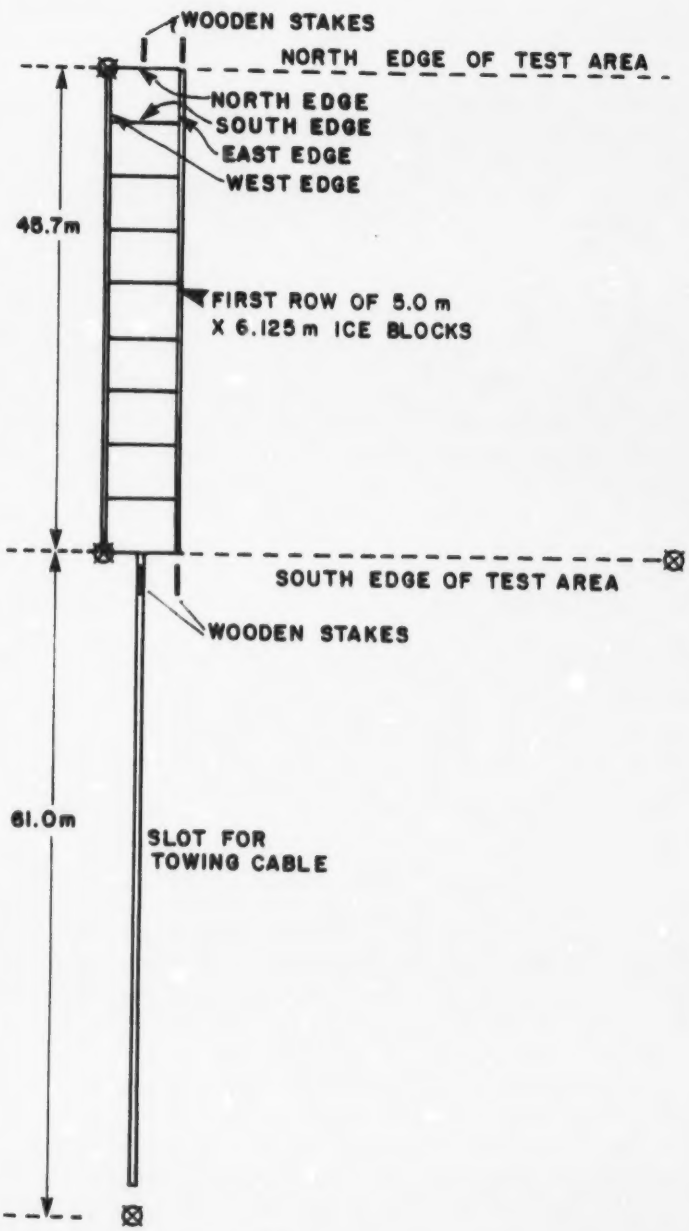


FIGURE 9

DIMENSIONS OF ICE BLOCK ROW

trench had been cut only for the west edge and part of the east edge of first row of ice blocks. The shovels and strainer were used to remove the slush and broken pieces of ice from the trenches to reduce the amount of refreezing that would occur overnight.

The following day, Saturday, April 7, a set of tire chains was improvised for the rear tires of the Ditch Witch using some small chain, steel cable and cable clamps (See Plates 15, 16 and 17). The steel chain was placed across the tire tread at equally spaced intervals and cables were threaded through the ends of the chain on each side of the tire. The cables were then tightened and secured with cable clamps. The additional traction on the rear tires of the Ditch Witch improved the cutting speed, although at times the machine did not move forward and the chains on each rear tire began to scrape a small hole in the ice.

While submerging the ice blocks on Sunday, April 8, it was observed that the ice consisted of two layers, a bottom layer of clear ice about 15 to 20 cm thick and a top layer of white ice about 46 to 56 cm thick. It was believed that the cutting teeth on the Ditch Witch were relatively dull, since the machine is normally used to dig trenches in earth rather than in ice, and that the teeth were not sharp enough to cut through the hard, clear ice in the bottom layer. A grinding wheel was rented the following day, and the teeth on the Ditch Witch were sharpened. The cutting speed increased dramatically to approximately 183 m/hr.

Once the west and east edges of each row of ice blocks had been cut with the Ditch Witch on Saturday, April 7, the south and north edges of the individual ice blocks were cut with chainsaws (See Plate 18). A single cut at an angle of 45° was used along each edge, since the trailing edge of one block was the leading edge of the next block.

The chainsaws were also used to cut a wide slot at the north edge of the test area to provide clearance for the first row of ice blocks. The ice in this slot was cut into small chunks, which were pushed under the surrounding ice. The pry bars and pike poles were then used to move the ice blocks towards the north edge of the test area and leave an open water slot between each block to minimize refreezing of the ice overnight. The wide slot was not needed for the subsequent rows of ice blocks, because one or more blocks could be pushed into the open water area left by blocks already towed under the surrounding ice, and the remaining blocks in the row could then be repositioned.

The 20 cm ice auger was used to manually drill holes in the ice blocks for the ice anchors. At first, this was a time-consuming process requiring much effort, and it was suspected that the cutting head on the auger was dull. A sharpening stone was used to sharpen the cutting head but only a small impovement was observed. An electric generator was later rented and the electric drill and drill bit were connected to the ice auger to speed up the drilling of the holes for

the ice anchors. Since the auger removes most of the slush and broken ice from the hole as it is drilling, very little refreezing occurred in the ice anchor holes.

The shovels and strainer were used to clear the slush and broken ice (See Plate 19) from the towing cable slot which had been cut by the Ditch Witch. Although this procedure reduced the amount of refreezing, the primary purpose was to improve the visibility in the slot and prevent jamming of the guide post while towing the ice blocks. Once some of the ice blocks had been towed under the surrounding ice, the towing cable slots were cleaned by simply pushing the slush and broken ice along the slot and into the open water area using the shovels.

The cutting of the ice blocks and towing cable slot proceeded rapidly, since the operations of trenching with the Ditch Witch, cutting the leading edges with the chainsaws and drilling ice anchor holes with the ice auger could be carried out simultaneously. However, as the open water area increased in size, the blocks which had been cut and left floating in the water began to drift with the wind. The task of maneuvering the ice blocks into position for the towing operations required more time as the open water area increased in size. However, the use of the hook and rope was found to be a suitable method of controlling the movement of the floating ice blocks.

3.2.2 Tilting and Submerging Process

Two types of towing equipment were assessed in the large scale tests. A log skidder was evaluated for 2 days, Sunday, April 8 and Monday, April 9, and a D-6 bulldozer with a winch was evaluated for 3 1/2 days, from Tuesday, April 10 to Friday, April 13. The techniques developed during the small scale tests for tilting and submerging the ice blocks were initally applied in the large scale tests with the skidder.

The ice blocks in the first row were tilted using the tripod and two ice anchors, one near the leading edge and one near the trailing edge (See Plate 20). The tripod was placed near the leading edge and the cable from the rear ice anchor was placed over it. The cable from the front ice anchor was left slack. Once the leading edge of the block was tilted below the surrounding ice, the tripod was moved to the center of the block and the block was tilted further (See Plate 21). The tripod and rear ice anchor were then removed (See Plate 22) and the block was submerged by pulling from the front ice anchor. Although this procedure worked smoothly, it was found to be fairly slow because of the time required to slacken the cables, move the tripod, change the cable connections and remove the rear ice anchor and tripod for each ice block being towed.

During the tests with the bulldozer, the noticeable increase in pulling power led to the decision to use only a single ice anchor located slightly forward of the center of the block. The tripod was

placed near the leading edge and the block was tilted below the surrounding ice. The tripod was then removed and the block was submerged by pulling from the ice anchor. This modified procedure increased the speed of the towing operations considerably and was used for most of the ice removal operations. The single ice anchor without the tripod was also tested and found to be the fastest method of tilting and submerging the ice block.

However, during the tests with the larger blocks and during the final days of the testing when the ice was weaker, it was found that the blocks tended to break into pieces if only a single ice anchor was used. The previous method involving two ice anchors was used in the final days of the testing, but the cable connections were modified slightly to speed up the operations. An ice anchor with a short cable was installed near the trailing edge with its cable hooked onto the towing cable so that it could be quickly disconnected. An ice anchor with a long cable was installed near the leading edge with its cable shackled to the towing cable. This front ice anchor would remain shackled to the towing cable at all times, but because of its longer connecting cable would not carry any load until the rear ice anchor was removed.

A videotape camera was rented in the final days of the testing to record the ice removal operations. The tilting and submerging process for the tripod and single ice anchor method is illustrated in the video tape sequence in Appendix B (Plates 26 to 39). The technique in which the tripod is not used is illustrated in Plates 40-43.

3.2.3 Towing Procedures

Although a backhoe was used to provide the towing force during the small tests on single ice blocks, the large scale tests required a different type of machine. Since a large number of blocks would be towed under the ice, the cable slot would be quite long and the blocks would be stored in a series of long rows. Some of the blocks must be towed a great distance under the ice and the use of winching equipment was considered to be the most efficient method. As discussed in the previous section, two types of towing machinery were evaluated, a log skidder and a D-6 bulldozer with a winch.

The log skidder was driven onto the ice near the shoreline and the brakes on the rubber tires were set to prevent rolling. The pulley block and winch cable of the skidder were connected to the cables of the ice anchors on each block to be towed. The tripod and two ice anchors were used to tilt the ice block and the block was submerged by pulling only from the front ice anchor. The blocks were then towed along the cable slot until they hit the trailing edge of the preceding block.

Several difficulties were encountered during this test. The pulley block of the skidder frequently became jammed in the towing cable slot or became wedged between the ice block and the bottom sur-

face of the surrounding ice. The pry bars and pike poles were used to break the ice at the edges of the slot to free the pulley block.

In some cases, the block rotated while being towed, so that the hole for the ice anchor was no longer aligned with the cable slot. The front ice anchor and towing cable could only be retrieved by cutting the surrounding ice with chainsaws and lifting these pieces of ice out of the water. The ice anchor was then removed and the winch on the skidder was used to pull the cable out from between the ice block and the surrounding ice.

While tilting and submerging one of the ice blocks, the surrounding ice cracked along a line extending from the SW corner of the first row of blocks to the first cable slot. This wedge-shaped chunk of ice broke loose and was floating freely for the remainder of the testing. The ice blocks were pulled against this ice chunk during the tilting and submerging process, causing it to slide sideways due to its wedge shape. Although this did not affect the tilting and submerging of the ice blocks, the sideways motion of the chunk of ice tended to close the cable slot so that the pulley block became jammed. Chainsaws were used to free the pulley block and two short pieces of timber were placed in the slot to keep it from closing again.

Since the wedge-shaped chunk of ice was floating freely while the surrounding ice was weighted down with snow from the recent storm, the bottom of the ice chunk was higher than the bottom of the surrounding ice. When the submerged ice block was towed along the cable slot, it slid along the bottom of the floating ice chunk then became jammed against the protruding edge of the surrounding ice. The block was freed by using the blade on the Ditch Witch to push snow on top of the ice chunk (See Plate 23) until the ice block was submerged below the obstruction and the towing was resumed. Before continuing with the next block, shovels were used to remove snow from the chunk of ice until it was floating at the same level as the surrounding ice. This corrective action seemed to eliminate this problem, however, the pulley block continued to become jammed in the cable slot whenever the pieces of timber in the slot were jarred loose.

Due to the difficulties encountered, only 7 ice blocks were towed under the ice on the first day of testing the skidder. In order to eliminate the problems related to the jamming of the pulley block, the decision was made to use a larger cable in place of the light cable and pulley block of the skidder. Unfortunately, a large part of the second day of testing the skidder was spent in travelling to the town of Timmins to purchase the cable, then installing the cable on the winch. During this time, additional rows of ice blocks were measured and marked. The Ditch Witch was used to cut trenches for the cable slots and sides of the ice blocks. The leading edges and ice anchor holes for the individual blocks were also completed using the chainsaws and ice auger.

When the new cable was installed on the winch, the towing operations were resumed with the skidder positioned at the end of the second cable slot. Since the mechanical advantage provided by the pulley block was no longer available, a more powerful pulling force was required from the winch. Numerous attempts were made to tilt and submerge the ice block and at one point the end of the cable was pulled loose from the winch. The cable was reattached and the attempts to tilt and submerge the ice block finally succeeded. Once submerged, the block was towed to the end of the slot without any jamming problems.

However, the attempts to tilt and submerge the next ice block were not successful. The operator of the skidder was reluctant to apply additional power to the winch because he suspected that the equipment was operating at its peak capacity. Although this opinion was questioned, the operator was convinced that further increases in power would damage the winch or break the cable. The testing of the skidder was terminated at this point and arrangements were made to begin the testing of the D-6 bulldozer and winch.

The bulldozer was positioned at the end of the second cable slot and the cable was connected to the ice block which the skidder was unable to submerge. The ice block was easily tilted, submerged and towed to the end of the cable slot. However, the ice block was towed so rapidly that it momentum caused it to slide below the previous ice block already stored underneath the surrounding ice. Chainsaws were used to retrieve the front ice anchor and towing cable.

While towing the ice blocks, the operator frequently backed the bulldozer onto the ice and pulled with the winch, then drove forward to pull with the tracks. At one point, he moved the bulldozer too far onto the ice, causing it to crack and break. The bulldozer did not sink into the water very far (See Plate 24) possibly because of the support provided by the two ice blocks under the ice at that location. However, the towing operations were suspended for several hours while a D-7 bulldozer was brought to the lake to pull the D-6 bulldozer out of the water.

There was no damage to the bulldozer and the towing operations were resumed. Due to the delays encountered, only 8 ice blocks were towed under the ice in a period of less than half a day. During the next two full days of testing, no serious difficulties or delays were encountered and approximately 20 and 24 blocks per day, respectively, were towed (See Plate 25).

The towing operation was modified only slightly in order to reduce the time spent in retrieving the ice anchors when the ice anchor hole was not aligned with the cable slot. A short piece of timber was inserted in the ice anchor hole as the block began to move along the cable slot. The timber post was held vertically in the slot while the ice block was towed toward the shore. The post was then removed and the ice anchor was easily retrieved.

This post was frequently broken and replaced as the ice blocks rotated while being towed. A thin-walled pipe was eventually used to guide the ice block along the slot. During the tests using the tripod and a single ice anchor, this guide post was inserted in the ice anchor hole when the ice block was tilted. The corners of the cable slot were also cut at an angle with chainsaws so that the guide post would tend to slide into the slot as the block was submerged.

During the towing operations, the ice between the slots cracked as the blocks were tilted and submerged. These large rectangular pieces of ice floated free throughout the remainder of the testing, but did not cause any difficulty. When maneuvering the ice blocks into position at the end of the slot the large rectangular pieces tended to drift out of position, but this was only a minor problem. The mobility of these large pieces was an advantage because the slot being used could be widened by simply pushing these pieces apart before the block was tilted. The pulling force on the ice block then held the large piece in place as the ice block was tilted and submerged. The slot could easily be widened again as the block was towed along the slot. As the slots became filled with the ice blocks, the large pieces were eventually held in place by positioning one of the submerged blocks underneath the crack in the ice.

Since several of the ice blocks had broken during the final days of the testing, attempts were made to tow these pieces on top of the surrounding ice. A chainsaw was used to cut the leading edge at a 45° angle in the reverse direction so that the ice pieces would tend to lift out of the water when towed. A hole was drilled in the center of the ice pieces using the ice auger, and the ice anchor was laid across the hole. The cable of the ice anchor was dropped through the hole and a pike pole was used to lift the cable out of the water. The end of the ice anchor cable was connected to the towing cable and the winch was used to pull the ice pieces on top of the surrounding ice. Although it was originally planned to pull these ice pieces towards the shore, most of the pieces broke as they emerged from the water and landed on top of the surrounding ice. This operation was terminated and the remaining ice pieces were left floating in the open water area.

On the final day of testing, the towing operations were terminated after only half a day, because the warm weather had weakened the ice to the point where it was no longer considered safe to operate the equipment on the ice. The remainder of the day was spent in demobilizing, loading equipment into the truck and returning all rental equipment. However, since no additional difficulties had been encountered, it was believed that the remaining blocks which had been cut could have been towed under the ice, so that a total of approximately 21 blocks would have been cleared on the final day of testing. The open water area produced during the large scale testing was approximately 46 by 57 m in size.

3.3 Discussion of Results

3.3.1 Marking, Cutting and Maneuvering Techniques

During the large scale tests, the snow on the ice initially created difficulties in walking and moving equipment from the truck to the lake. However, the use of the snowmobile and sled speeded up the operations considerably. The snowmobile was particularly useful for installing the line of warning stakes across the lake and for towing the long lengths of rope used to measure and mark out the entire ice testing area. However, the pieces of tape attached to the rope as distance markers were pulled loose when the rope was dragged through the snow. The pieces of tape were replaced with fluorescent paint sprayed directly on the rope, and this method worked reasonably well. The problems created by the presence of snow were eliminated once a path to the lake was cleared and the ice in the test area was scraped clean using the Ditch Witch. In any future work it may be useful to attach a larger blade to the front end of the Ditch Witch to increase its effectiveness in clearing snow.

The measuring and marking of the ice blocks was initially performed using a measuring tape and fluorescent paint to mark the edges of each block. However, the lines tended to deteriorate and become indistinct because of the water on the ice. During the later stages of the project, the painted lines were replaced with a line scratched into the ice with a pike pole. This method worked reasonably well, but the lines were not as straight as before. In future work, a special tool for etching lines in the ice should be designed and fabricated. The measurement of the ice blocks may be speeded up by using ropes previously marked with spray paint at intervals corresponding to the block sizes.

In marking the locations for the cable slots, an additional distance of 1 m was included as clearance between the slots to prevent the block being towed along the slot from hitting the edges of the blocks stored in adjacent rows. This clearance distance also produced a heavier piece of ice between the cable slots so that the weight of this ice piece would be more effective during the tilting of the ice blocks. In future work, it is suggested that an even wider distance should be left between the cable slots. The length of the cable slots can be increased to provide space for storing any excess rows of ice blocks which may be produced.

The large wedge-shaped piece of ice which broke off the corner of the first cable slot (See Figure 10a) presented several difficulties. Short pieces of timber were used to keep the wedge from sliding sideways and closing off the cable slot, and snow was used to weight the ice piece so that it would float at the same level as the surrounding ice. The pieces of timber frequently floated free and the cable slot was closed as the tilting ice block pushed the wedge sideways (see Figure 10b). If this problem occurs in future work, it is suggested that the situation may be corrected by using chainsaws to cut the

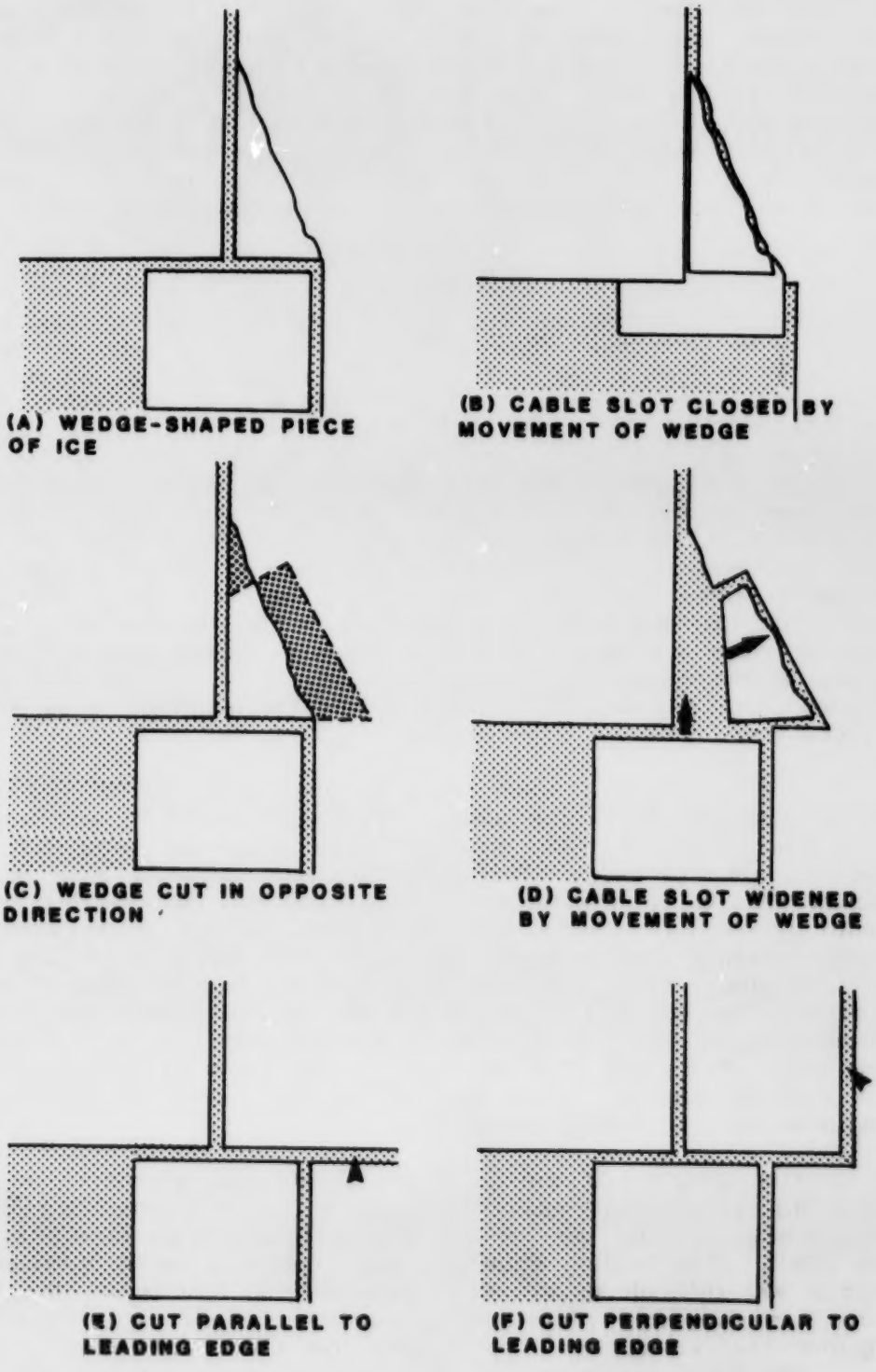

(A) WEDGE-SHAPED PIECE OF ICE
(B) CABLE SLOT CLOSED BY MOVEMENT OF WEDGE
(C) WEDGE CUT IN OPPOSITE DIRECTION
(D) CABLE SLOT WIDENED BY MOVEMENT OF WEDGE
(E) CUT PARALLEL TO LEADING EDGE
(F) CUT PERPENDICULAR TO LEADING EDGE

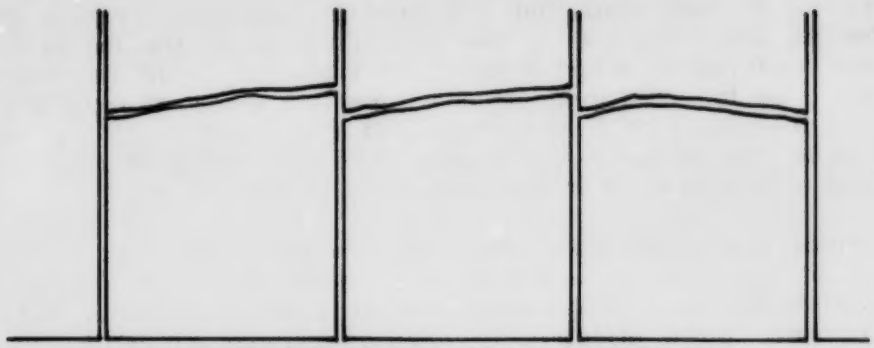
FIGURE 10
WEDGE-SHAPED PIECE OF ICE

wedge in the opposite direction as shown in Figure 10c. The sharp corner of the wedge can be removed and the surrounding ice can be cut wider to allow the modified wedge to slide in the opposite direction to widen the cable slot as shown in Figure 10d. It was suspected that the wedge-shaped crack in the ice was originally produced at the first row of ice blocks because the surrounding ice was not free to lift upward as the ice blocks were submerged under this corner. In future applications, it is suggested that the surrounding ice near the first row of ice blocks should be cut parallel, then perpendicular to the leading edge as shown in Figures 10e and f. It is expected that this action may prevent the formation of the wedge-shaped cracks in the ice.

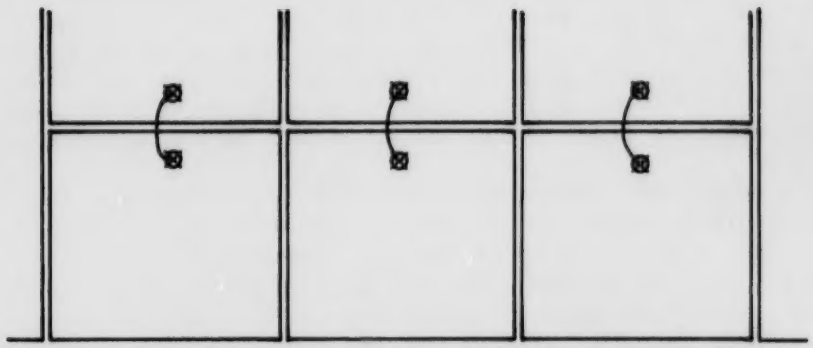
The second and subsequent rows of ice blocks did not produce wedge-shaped cracks in the surrounding ice. However, the ice between the cable slots cracked to form large rectangular pieces of ice as shown in Figure 11a as the ice blocks were submerged and towed along the cable slots. The floating rectangular ice pieces did not present any difficulties and in some cases were useful since they could be pryed apart to widen the cable slot as desired. In any future work, it is suggested that this procedure can be controlled by using chainsaws to cut the ice parallel to the leading edge as shown in Figure 11b. The straight cut is expected to prevent these pieces from sliding sideways to close the cable slots and to allow the pieces to be pryed to widen the slots if necessary. The rectangular piece can be kept from drifting away by a rope attached to two stakes installed in the ice using a small ice auger. If sideways motion of the rectangular pieces is not required, the chainsaws can be used to produce angular pieces which will be held in place by the surrounding ice as shown in Figure 11c.

During the small scale tests, all cutting of the ice was accomplished with the power chainsaws. This work was both strenuous and time consuming, especially since two cuts had to be made and the ice between them removed. This procedure was necessary to allow a sufficient area of open water for maneuvering the block and to prevent rapid refreezing. Since the Ditch Witch cuts a 15 cm wide path, double cutting was no longer required. The Ditch Witch was able to cut the sides of the ice block rows and the trailing edge of the last ice block, as well as the slot for the cable. This process left only the angled cut at the leading edge of the ice blocks to be cut with the chainsaws. Since only one chainsaw cut per ice sheet was necessary, a decrease of about 92% was obtained in the amount of manual labour required for the cutting of ice.

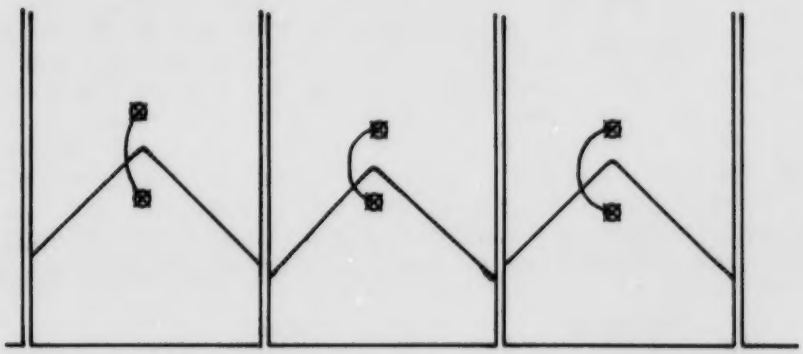
The accuracy of the Ditch Witch cuts was adequate, but problems did result from crooked chainsaw cuts. A number of times the angled leading edge was not cut to a sufficient angle to submerge the ice block. The leading edge was often cut at a nearly vertical angle and it was difficult to submerge these blocks. At times, the leading edge was also cut crooked so that only the corners of the block rested against the surrounding ice during the tilting operation. It was



(A) BROKEN RECTANGULAR PIECES



(B) RECTANGULAR PIECES CUT WITH CHAIN SAW



(C) ANGULAR PIECES CUT WITH CHAIN SAW

FIGURE 11

RECTANGULAR PIECES OF ICE

suspected that this situation may have caused these blocks to break since the applied forces were concentrated on the corners of the blocks. It is suggested that a lightweight aluminum bracket could be attached to the chainsaw so that it would rest on the ice to keep the chainsaw inclined at a 45° angle. This bracket could be designed to ride along on top of a long piece of pipe laid across the surface of the ice. In this way, both the angle and the direction of cut would be fixed while the operator would still have the option of lifting up the chainsaw at any time, if it becomes stuck in the ice.

Since the cable slots could accommodate more blocks than were cut out of one row, it was frequently necessary to maneuver the ice blocks through the open water area to a previous cable slot. The prybars were quite effective in prying a single ice block loose from the row of blocks cut with chainsaws. The pike poles could also be used for prying, but were primarily used to push and pull this ice block once in the open water area. The remaining ice blocks in the row were then easily pried apart and left freely floating. During the large scale testing, the blade on one of the prybars and the wooden handle on one of the pike poles were broken, but the others were undamaged. In future applications, it is suggested that some additional prybars and pike poles should be produced as replacement parts.

As the open water area increased in size and the ice blocks began to drift apart, it became more difficult to maneuver the ice blocks into position for the towing operations. A steel hook was placed in the ice anchor hole of the ice block to be moved and the attached rope was pulled toward the cable slot by hand. In some cases, it was possible to pull the ice block behind other free floating blocks or to use the pike poles to drag nearby blocks along with the block being moved. The hook and rope system was quite effective, however it was observed that the hook often tended to slip out of the ice anchor hole. It is suggested that the design of the hook should be slightly modified in future applications by lengthening the pointed end and changing the bend in the hook to a much sharper angle. Alternatively, the hook may be replaced with a lightweight version of an ice anchor. The maneuvering operation may also be simplified by using a rope to join each row of blocks together before they drift apart, so that the entire row can be maneuvered into position as a single unit. The individual blocks can then be disconnected in turn and positioned in front of the cable slot for the towing operation.

3.3.2 Tilting and Submerging Process

Considerable manpower was required to position and hold the ice block so that the ice anchors and tripod could be transferred to the ice block and installed. In future work, ropes could be installed to hold the ice block in this position. Insertion of the ice anchors through the ice blocks was performed rapidly, but the positioning of the ice anchor pipe so that it was oriented parallel to the long axis of the sheet required some effort. If the cable was held in proper orientation as the ice anchor was inserted, the pipe would usually fold out

in the proper direction. Once deployed, if the cable was given a quick jerk, the pipe would hit the underside of the ice producing a sound indicating the orientation of the pipe. If this was unclear, the slush from the hole could be removed and the pipe positioned visually. To maintain this alignment, some tension was required to hold the pipe against the underside of the ice. Alternatively, the cable could simply be dropped into the water and the weight of the sagging cable would be sufficient. If two ice anchors were being used, their ropes would be tied tightly together to provide sufficient force to hold the pipes properly aligned.

Positioning of the tripod was a more difficult task than in the previous tests. Using cable instead of chain, the tripod was no longer held fast at the top, but could tip forward or backward or collapse if not positioned properly. To overcome these problems, it is suggested that the legs be chained together. A hook would be attached onto the rear leg allowing for disconnection when the tripod gets jammed. With the tripod essentially fixed, greater angles between the front and rear legs could be used in order to reduce the risk of tipping.

. Various combinations of tripod and ice anchor arrangements for tilting and submerging the ice blocks were evaluated during the large scale testing. The method using a single ice anchor slightly forward of the center of the block, with no tripod, was the fastest procedure, but the blocks tended to break more frequently. The method using a single ice anchor with the tripod was the second fastest procedure, but some of the blocks were also broken with this method. The use of the tripod and two ice anchors was the slowest procedure, but was considered to be the best method for reducing the number of ice blocks which break into pieces. In any future work, it is suggested that the single ice anchor with no tripod should be initially used, but if the ice blocks begin breaking, the tripod and two ice anchors should be used.

The experience of the winch operator was found to be an important factor in the towing operations. When the ice block became jammed, it was observed that a continuous pull was not as effective as a pumping action in freeing the block during the tilting operations. Judgement was also needed in controlling the towing speed of the block and stopping the block at the end of the row of submerged blocks.

3.3.3 Towing Procedures

The towing configurations used in the small scale tests included the use of an electric winch and the hoe mechanism of a rubber tired backhoe. The maximum towing force developed by these means was generally the factor limiting the maximum size of ice block used. Even the log skidder used in the full scale tests with a rated winch pull of 44,480 N (10,000 lbs) experienced considerable difficulty. It was only with the D-6 bulldozer that ice strength rather than winching capacity became the limiting factor.

Conditions are not always ideal and the winch must be able to compensate for these imperfections in the towing operation. Conditions such as snow on the surface of the ice or non-perfect alignment of the ice guide with the slot led to a dramatic increase in pull required. It should also be remembered that the pulling capacity of winches is rated for the first roll of cable on the drum. As the distance from the centre of the shaft increases, the pulling forces decrease proportionately. In addition, on older machinery equipped with hydraulic winches, relief valves and hydraulic pumps may be worn, resulting in a further decrease in winch efficiency.

Clearly the D-6 bulldozer winch, which was rated at 232,186 N (52,200 lbs), was larger than that required. A smaller bulldozer with a winch probably would have been sufficient although traction on the ice might be a problem due to its reduced weight.

A two line pulley system could result in a further reduction of required winching capacity. To overcome the problem of the pulley getting stuck in the trench or between the ice blocks, a guide could be fabricated and bolted to the pulley. This guide would follow the cat'e slot and hold the pulley above the water. A two line system would, however, result in a decrease in towing speed with no significant improvement in ease of cable handling. Cable handling required considerable manpower during the full scale tests. Two to three men were required to pull the cable and ice anchor back into position for towing. A small portable winch similar to the one used in the first test could prove very useful for this task in future work.

The problem of keeping the ice anchor hole aligned with the cable slot was solved by inserting the guide post in the ice anchor hole. However, the wooden posts were frequently pulled loose or broken when the post became jammed in the slot. The thin-walled pipe which replaced the wooden posts was slightly heavier and was more difficult to dislodge from the ice anchor hole. However, this guide post was inserted in the ice anchor hole as soon as the leading edge was tilted below the surrounding ice, and in one instance, the guide post became wedged between the ice block and the surrounding ice as the block was submerged. The guide post was easily bent to a right angle and the ice anchor hole was no longer aligned with the cable slot. Although chainsaws can be used to retrieve the ice anchor in this situation, the process of cutting and lifting pieces of ice out of the water to find the ice anchor hole is very time-consuming. In any future work, it is suggested that the guide post should be constructed of stronger material and that a large set of ice tongs should be specially designed for lifting heavy pieces of ice out of the water. The water depth at the end of the cable slot should be sufficiently deep to allow easy removal of the ice anchors.

In the later stages of the ice testing, the entrance to the cable slot was widened by using the chainsaw to cut off the corners, to prevent the guide post from becoming wedged between the ice block and the surrounding ice. The post slid along the edge of the ice and

entered the cable slot as the ice block submerged. In future applications, it is suggested that the entrance to the cable slot should be made large enough to permit the tripod to move through the entrance. This modification will allow the ice block to submerge further beneath the surrounding ice and will reduce the risk that the ice block will slide back out when the tension in the cable is slackened off. The wider entrance will prevent the legs of the tripod from becoming wedged between the ice block and the surrounding ice, and may also reduce the damage to the tripod.

During the tilting operation, some of the ice blocks broke into pieces. In some cases, the larger pieces could be towed under the ice by continuing to pull on the ice anchors. One of the blocks which had broken in half was successfully towed under the ice by installing an ice anchor only in the rear half and pulling it towards shore so that it would push against the front half which was floating freely. However, in most cases, the broken pieces were left floating in the open water area. The attempts to tow the broken pieces on top of the surrounding ice were not successful, since these pieces generally broke apart as they landed on top of the ice. In future applications, it is suggested that a backhoe could be used to push these broken pieces under the surrounding ice as in the small scale tests. Alternatively, a larger area can be cleared and the broken pieces can be stored in a small section on the edge of the main open water area.

3.4 Cost Analysis of Large Scale Tests

The large scale tests of the ice-block-under-ice concept can be used to estimate the cost of the ice removal operations per unit area of ice cleared. These costs estimates will be useful in any future evaluation of this method for specific application at a particular harbour. Since the initial days of the large scale testing were spent in evaluating towing equipment and developing techniques for the application of the procedures on a large scale, the estimates of the rate of ice removal will be based only on the last three days of testing. The costs of equipment, personnel, supplies and services will be computed on a daily basis and divided by the average area of ice removed per day to obtain a unit cost based on the size of the open water area to be produced. This unit cost may be useful in estimating the expense of clearing ice from a specific harbour location using this method, or in comparing the economic benefits of this method with other techniques such as air bubbler systems.

The daily costs for leased equipment, personnel, supplies and services are summarized in Table 3. (The costs related to purchased equipment are also listed in this table, but are not included in the calculation of the cost per day of the ice removal operations. In applying these estimates to a specific application, the cost of the purchased equipment can be included by averaging over the expected duration of the ice removal operations.) The total cost per day is estimated to be approximately $2,500.

TABLE 3

ESTIMATED DAILY COSTS OF ICE REMOVAL OPERATIONS
AND COSTS OF PURCHASED EQUIPMENT

Leased Equipment	Daily Rate
1 Ditch Witch	$ 175
1 bulldozer with operator	440
1 electric generator	25
1 snowmobile	35
2 chainsaws	70
1 ice auger	25
	770
Personnel	
1 Field supervisor	290
4 Field personnel	1,000
	1,290
Supplies	
45 litres gasoline	20
2 litres chainsaw oil	5
Miscellaneous hardware	50
	75
Services	
Accommodations (5 people)	100
Meals	170
Transportation	95
	365
TOTAL DAILY COST	$2,500

Purchased Equipment	Cost
Guide post	$ 150
Cables and hooks	500
Rope	100
4 ice anchors	500
1 tripod	300
Pike poles, prybars, etc.	300
Timbers, stakes, etc.	150
TOTAL COST	$2,000

4. RESULTS OF FEASIBILITY STUDY

4.1 Equipment and Techniques for Full Scale Operations

4.1.1 Marking, Cutting and Maneuvering Techniques

Based on the results of the small and large scale tests, it is suggested that the following equipment and techniques be used during full scale operations:

1. Snow removal was found to be an important requirement of the ice-block-under-ice technique. The blade on the Ditch Witch worked well but a larger blade would prove more effective. If snow removal requirements are considerable, a different technique using another type of equipment would be required.

2. A rope which has been sprayed with paint at intervals corresponding to block sizes should be used to mark the rows of ice blocks.

3. A lightweight bracket should be attached to the chainsaws to maintain the angle of the blade at an angle of 45° to the ice surface.

4. The Ditch Witch should be used to cut the sides of the ice blocks, the slot for the towing cable and trailing edge of the last ice sheet. Chainsaws may then cut the leading edge of the blocks at a 45° angle.

5. The Ditch Witch should be fitted with tire chains to improve traction, and the cutting teeth should be sharpened.

6. The possibilities of modifying the Ditch Witch to include a rotating cutting assembly or a hydraulic winch should be investigated.

7. A special strainer or pumping system for cleaning slush and broken ice from the trenches cut by the Ditch Witch should be designed and fabricated.

8. An electric generator, power drill and ice auger proved effective for drilling holes in the ice sheets. Gas driven ice augers should be investigated for further work since they would be more portable.

Although the mass of the ice blocks was quite large, once cut free they are easily maneuvered by one person. However, as the open

water area increased, so do the problems associated with sliding blocks into position for towing. Prevailing winds, water currents and the refreezing of the open water areas should be used to their best advantage to keep blocks against one edge of the solid ice so they are within the reach of the pike poles. The blocks can be tied together until they are required for towing but a system in which the blocks are towed under the ice as fast as they are cut is the most efficient procedure. This also reduces the risk that the cuts may refreeze before the blocks are towed.

Blocks may be maneuvered short distances with the use of pike poles (see Figure 12a) while greater distances are best handled by pulling on a rope attached to the block by an ice hook (see Figure 12b). The freeing of stuck ice blocks can be accomplished with the pry bars shown in Figure 12c.

4.1.2 Tilting and Submerging Process

Equipment required for submerging the ice blocks under the ice includes:

1. A tripod, which is used to tilt the leading edge of the ice block under the surrounding ice (see Figure 13).

2. Ice anchors (see Figure 14a), which are used to attach the towing cable to the ice block.

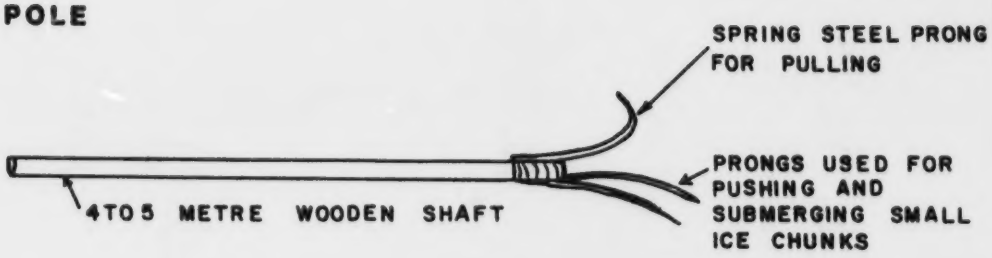
3. An ice guide (see Figure 14b), which is inserted into the hole in the ice block to keep the hole in the ice block aligned with the cable slot. This allows easy removal of the ice anchor once the ice block is pulled into its final resting position.

Three techniques have been developed for tilting the leading edge of the ice block under the surrounding ice. The selection of the procedure to be used in a given application will be dependent on the strength of the ice. The three techniques are:

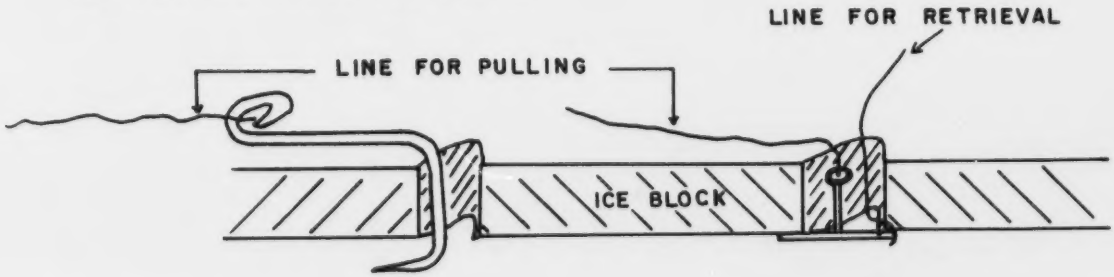
1. Two ice anchors with tripod

   Two ice anchors are inserted through holes along the centerline of the ice block, about one metre from the leading and trailing edges. The tripod is installed in the middle of the ice sheet with the cable from the rear ice anchor placed over the top of the tripod. Tension is applied to the rear ice anchor until approximately one half of the ice block is underneath the surrounding ice. This is the slowest technique but works well with relatively weak ice.

(A) PIKE POLE



(B) ICE HOOKS(2 DESIGNS)



(C) PRY BARS

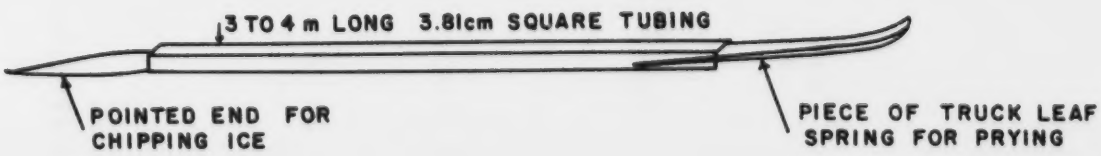


FIGURE 12

ICE MANEUVERING EQUIPMENT

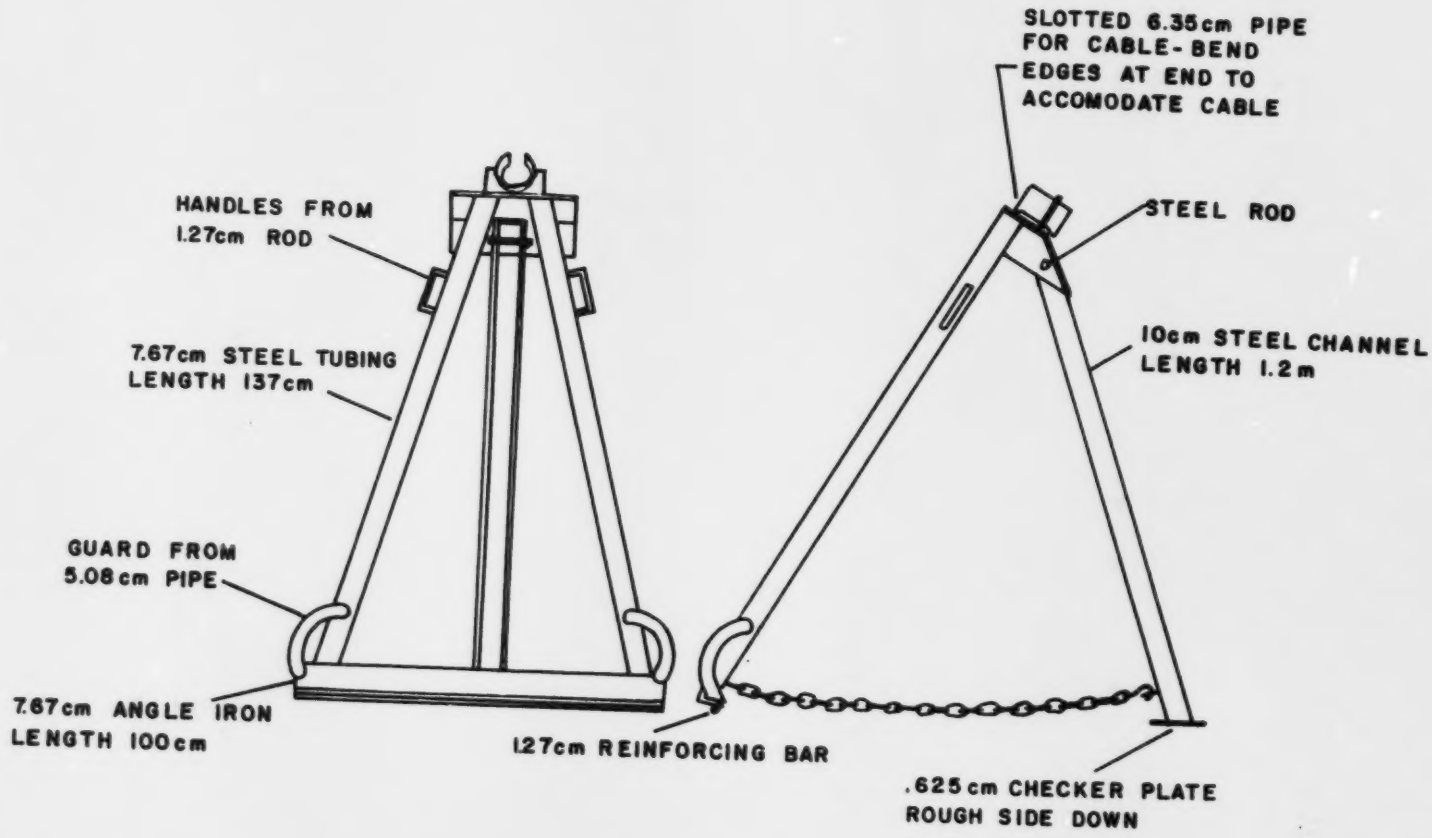
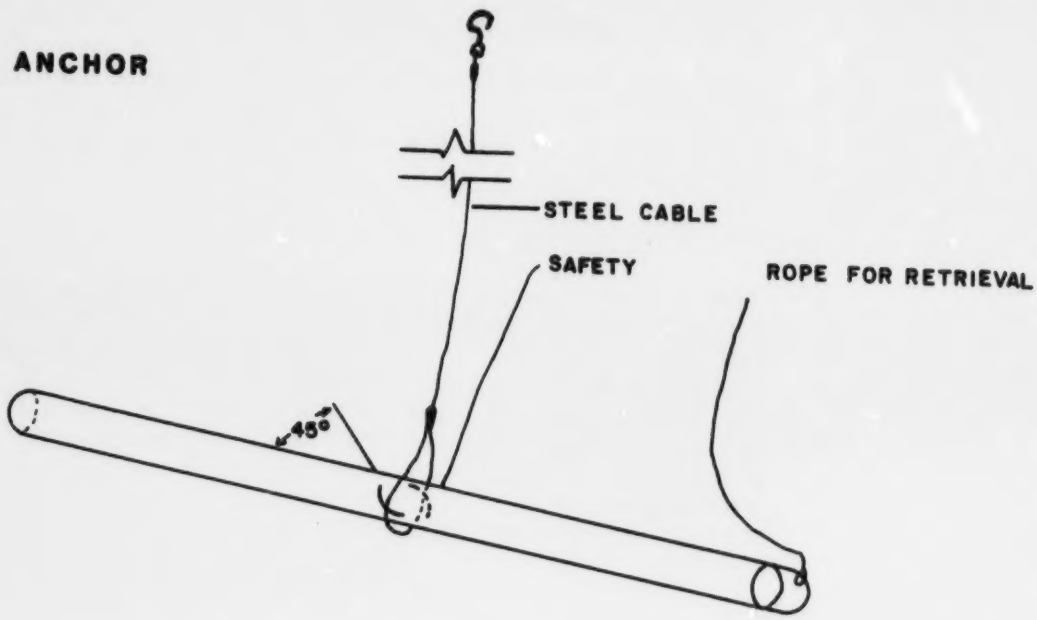


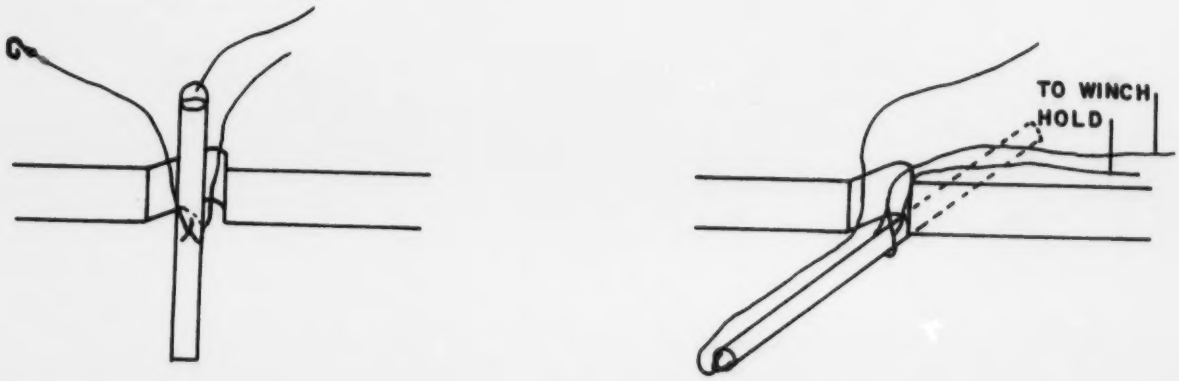
FIGURE 13

TRIPOD FOR ICE-BLOCK-UNDER-ICE REMOVAL TECHNIQUE

(A) ICE ANCHOR



INSERTION AND RETRIEVAL
THROUGH ICE SHEET



(B) ICE GUIDE

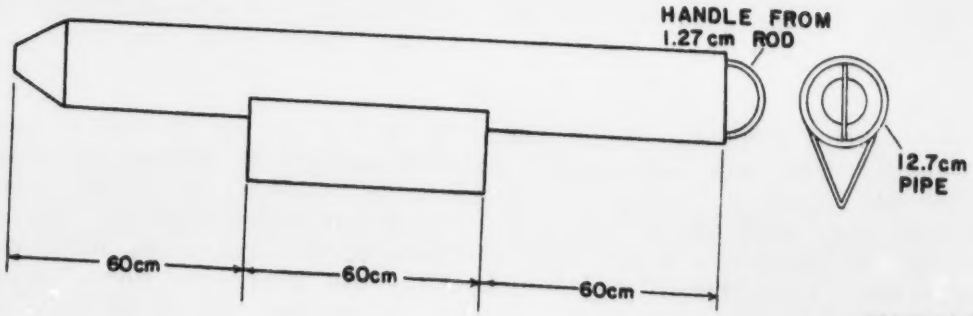


FIGURE 14

2. Single ice anchor with tripod

This procedure is illustrated in Figure 15. One ice anchor is installed slightly forward of the center of the ice block. (This procedure was the one most commonly used during the full scale tests.)

3. Single ice anchor

The third procedure involves one ice anchor placed slightly forward of the center of the ice block as in the previous technique, but the tripod is not used. Only the tension on the cable and the angled leading edge are used to force the ice block under the surrounding ice. Without the tripod, greater forces are required and as a result, a greater proportion of the ice blocks tend to break. Although this procedure, is the fastest method, it requires relatively strong ice and greater towing forces than the previous two methods.

4.1.3 Towing Procedures

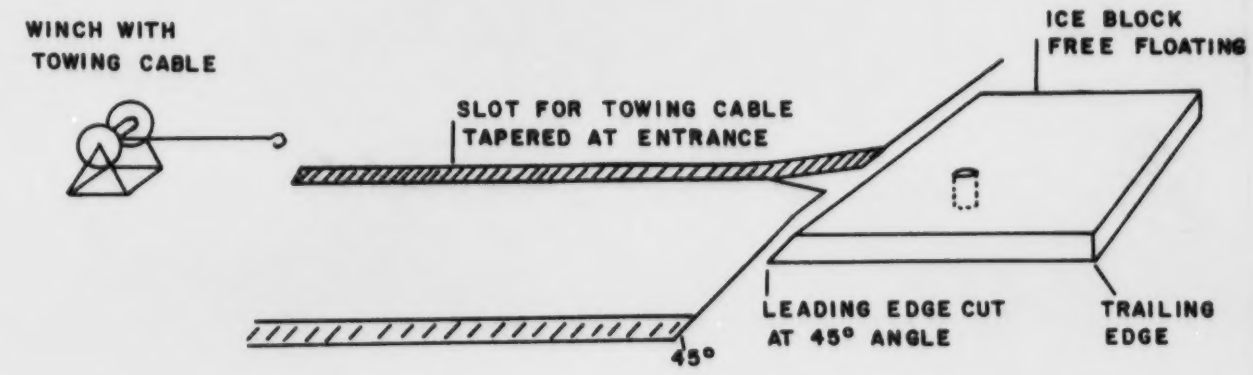
The towing cable and winching equipment should be sufficiently strong to overcome any imperfections in the system, such as snow on the ice surface or slight jamming. If a winch of sufficient strength is not available, a two line system utilizing a pulley may be used if the pulley is mounted on a special bracket, such as that shown in Figure 16. This bracket would ride along the slot cut for the cable to keep the pulley out of the water. It is suggested that for full scale operations, a small portable winch should be used to pull the cable, ice guide and pulley assembly (if used) into position for attachment to the next ice block. This would greatly reduce the physical effort and manpower requirements and increase the speed of the full scale operations.

4.2 Ice Removal Methods for Full Scale Operations

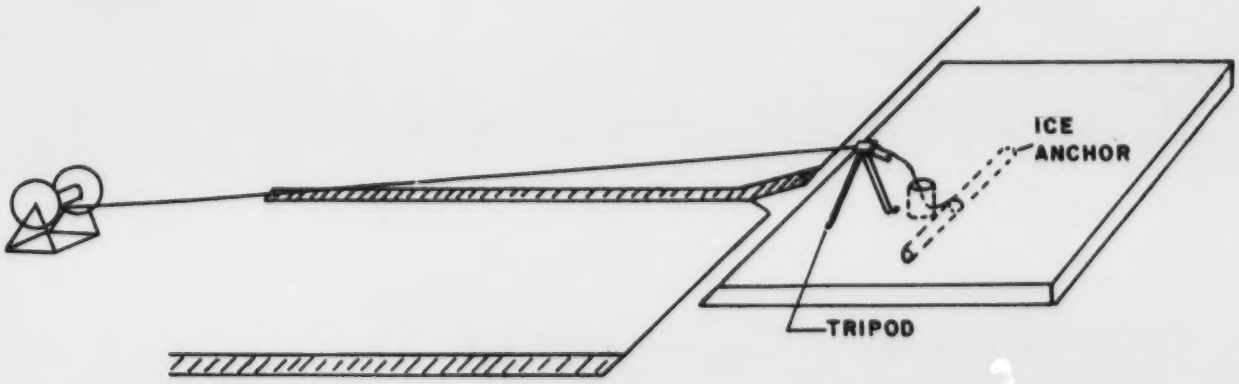
4.2.1 Removal of Landfast Ice

The ice-block-under-ice concept was initially conceived as a method for removal of landfast ice from berthing areas next to piers. Creating an open water area will expedite berthing, and reduce wear and tear on the hull, machinery, rudder stock and propellers of the cargo ships.

In some regions, the harbours to be cleared of ice may be located quite far from any open water areas traversed by ships, but may be realtively close to a channel broken by icebreakers. For example, during the small scale tests, it was found that a number of docks along the Miramichi River were surrounded by solid ice, although an icebreaker had broken a channel along the length of the river. In this situation, the procedures developed during the large scale tests



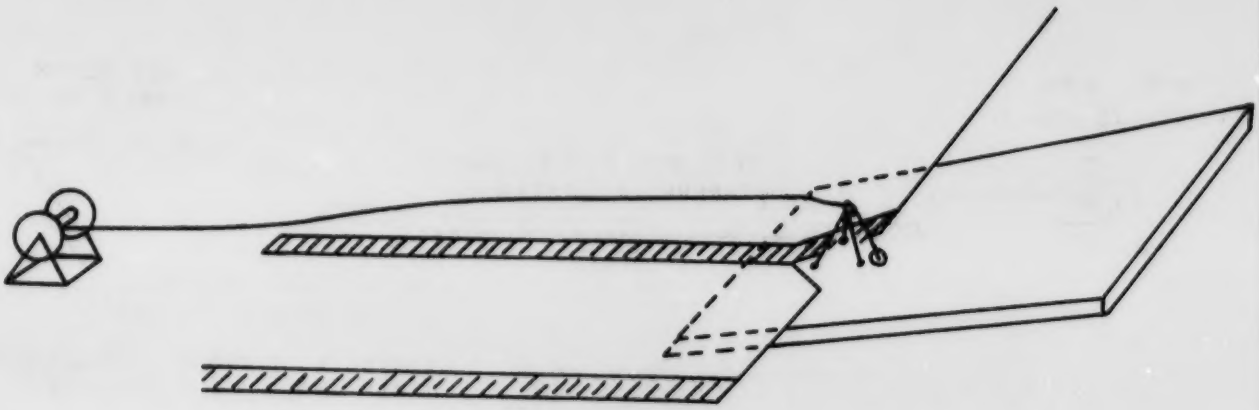
(1) ICE SHEET AND SLOT FOR CABLE CUT WITH THE USE OF DITCH WITCH AND CHAINSAWS



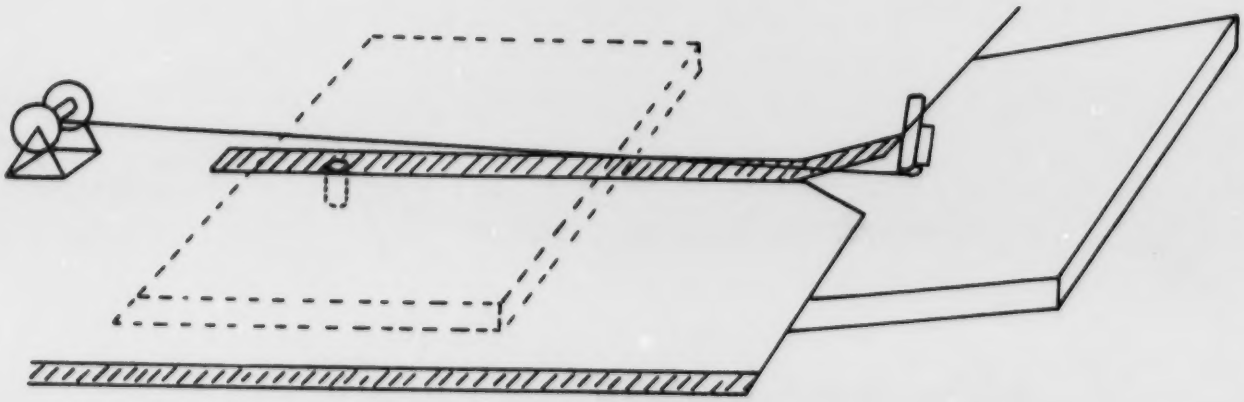
(2) INSERT ICE ANCHOR THROUGH HOLE IN ICE BLOCK.
PLACE FORWARD EDGE OF TRIPOD ABOUT 0.5 METRES FROM LEADING EDGE OF ICE BLOCK.
CONNECT TOWING CABLE TO ICE ANCHOR AND PLACE CABLE OVER TOP OF TRIPOD

FIGURE 15

APPLICATION OF ICE-BLOCK-UNDER-ICE CONCEPT



(3) APPLY TENSION UNTIL LEADING EDGE OF ICE BLOCK SLIDES UNDER SURROUNDING ICE. REMOVE TRIPOD.



(4) INSERT ICE GUIDE THROUGH HOLE IN ICE BLOCK PULL SHEET INTO ITS FINAL RESTING POSITION. REMOVE ICE GUIDE AND ICE ANCHOR.

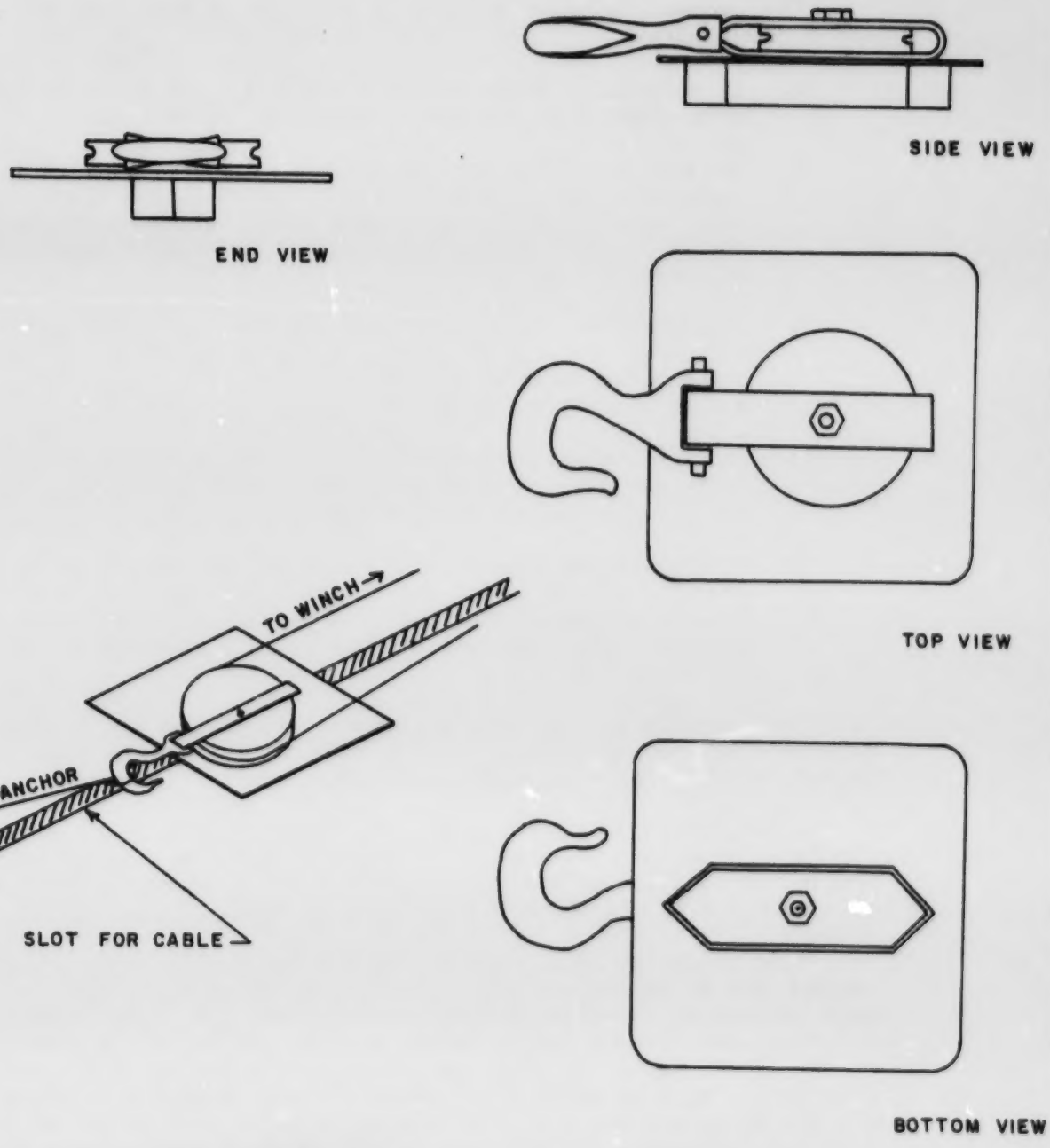


FIGURE 16

PULLEY BRACKET FOR TOWING CABLE

could be applied directly to produce an open water area which would provide access to the pier by ships entering the channel broken by the icebreaker.

The procedures to be followed in this type of full scale operation are outlined below:

1. If necessary, clear the snow from the ice surface over an area larger than the area of ice blocks to be cut.

2. Measure and mark the ice blocks in the area adjacent to the pier, and also mark the locations of the cable slots on the side opposite the pier. Leave additional clearance between the slots and increase the length of the slots to accommodate additional ice blocks.

3. Cut trenches along the sides of each row of blocks and along the cable slots. (If the ice along the pier is not free to move due to tidal action, the Ditch Witch can be used to cut a trench along the length of the pier.)

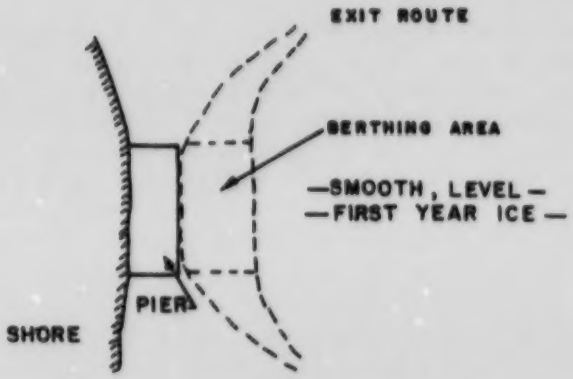
4. Use chainsaws to mark and cut the leading edge of the individual ice blocks at a 45° angle from the vertical and to cut off the corners of the entrance to each cable slot.

5. Position a bulldozer with a winch on the pier, then tilt and tow the blocks under the surrounding ice using the techniques previously described. The blocks can be towed in a direction away from the pier by using a pulley at the end of the cable slots.

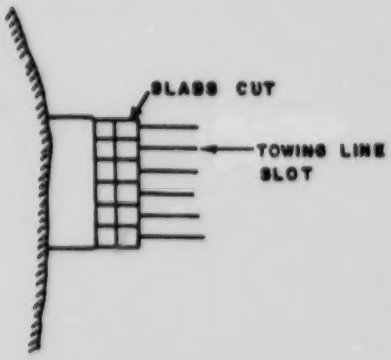
The marking and cutting of the ice blocks can be carried out independently and in advance of the maneuvering, tilting and towing operations to ensure a rapid and continuous speed of ice removal.

If necessary, this method can also be applied to clear an entry channel. If an exit channel is required, it could be cleared using a similar method prior to the ship departure. The sequential procedure for clearing harbours of ice is illustrated in Figure 17.

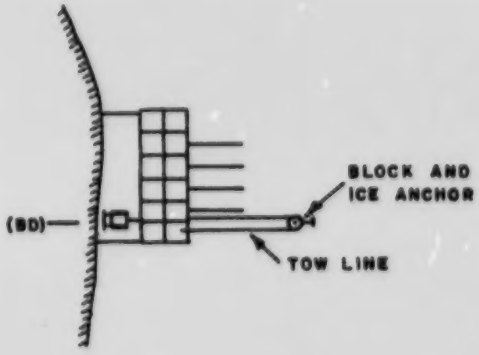
It is suggested that additional testing of the ice-block-under-ice concept should be carried out under Arctic ice conditions before full scale operations in Arctic harbours are carried out. The greater ice thickness will require larger cables and heavier towing equipment or smaller block sizes. If the ratio of the thickness to the horizontal dimensions increases quite significantly, it may become difficult to tilt and submerge the block due to rolling motions. The colder environment may also cause problems due to adfreezing of the ice block to the surrounding ice or rapid refreezing of the trenches and cable slots. Further small scale and large scale testing is recommended to investigate possible operational difficulties and solutions.



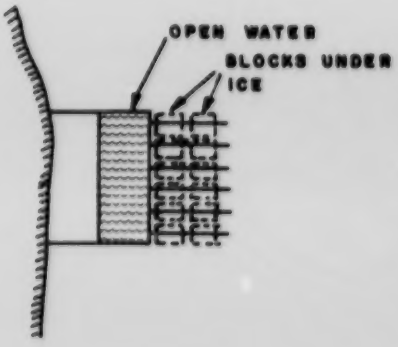
(A) PLAN VIEW OF PIER, HARBOUR CONDITIONS.



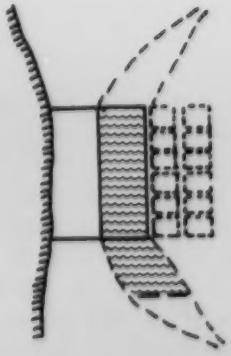
(B) CUTTING OF ICE AND SLOTS FOR TOWING CABLE.



(C) TOWING BLOCKS UNDER ICE USING BULLDOZER (BD) ON THE PIER.



(D) BLOCKS UNDER ICE.



(E) CUT ENTRY CHANNEL AND TOW BLOCKS UNDER. CUT EXIT CHANNEL (IF NECESSARY) PRIOR TO SHIP DEPARTURE.

(NOT TO SCALE)

FIGURE 17

SEQUENTIAL PROCEDURE FOR CLEARING HARBOURS OF ICE

4.2.2 Removal of Rough Ice Sections

Occasionally, the ice adjacent to the pier is not smooth, but consists of rough ice produced by the previous transit of a ship or icebreaker with subsequent refreezing of the broken ice. Previous discussions with Dr. Frederking of the National Research Council (NRC) indicated that the rough ice may be towed more easily than the smooth ice because the contact area between the towed block and the bottom of the surrounding ice is reduced. However, the large scale tests have demonstrated that the towing of the ice blocks is the least difficult aspect of the ice removal operations. It is suspected that the greater roughness of the ice block surface may increase the risk that the ice blocks may become jammed during the tilting and submerging process.

It is suggested that the rough ice near the piers should be cut into large floating slabs of rough ice which could be towed into an open water area produced by the ice-block-under-ice method to leave open water adjacent to the pier. A similar procedure could be used to clear the entry and exit channels, if necessary. Since sites with rough ice sections were not encountered during the site surveys for the field work, it was not possible to test the application of this method to this situation.

It is tentatively proposed that the rough ice sections adjacent to a pier (see Figure 18a) can be removed with the following procedure:

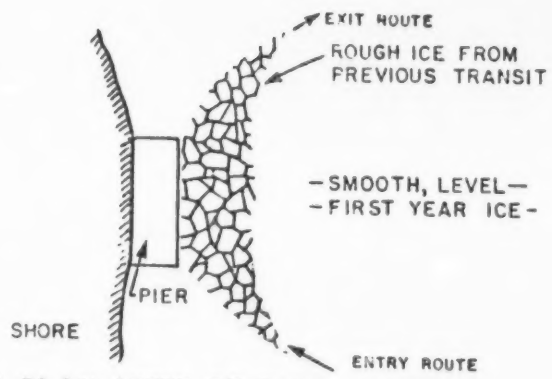
1. The techniques described for landfast ice can be applied to cut out an array of ice blocks and towing cable slots in the smooth ice (see Figure 18b), using a Ditch Witch and chain-saws.

2. The methods developed for landfast ice can be used to tow the ice blocks under the ice using a bulldozer with a winch on the pier (see Figure 18c).

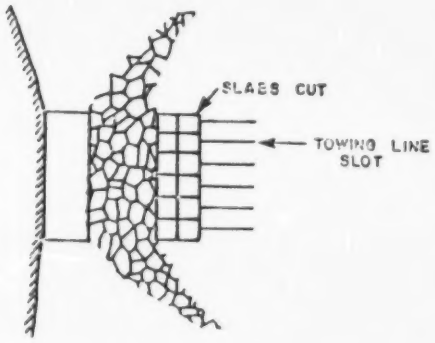
3. As the blocks are being towed under the surrounding ice, the Ditch Witch can be used to cut out the rough ice section (see Figure 18d).

4. The bulldozer and winch on the pier can be used to tow the rough slab into the vacated open water area, leaving open water near the pier (see Figure 18e).

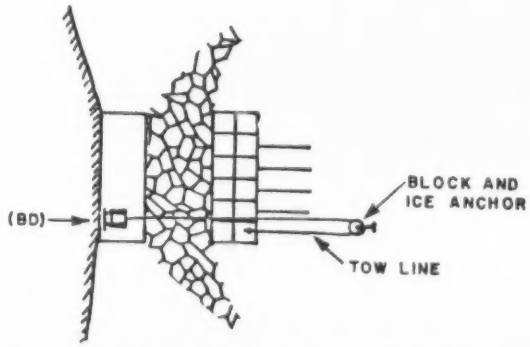
5. The rough slab can then be held in place with ice anchors. If necessary, this procedure can also be applied to clear an entry channel (see Figure 18f). If an exit channel is required, it could be cleared using a similar procedure prior to the ship departure.



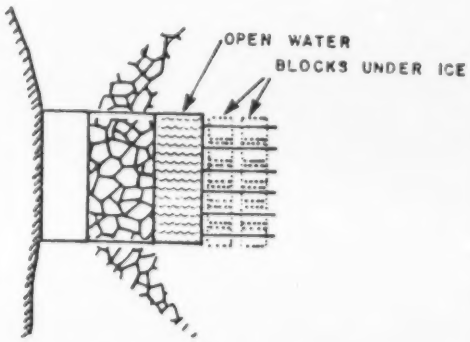
(A) PLAN VIEW OF PIER, HARBOUR CONDITIONS.



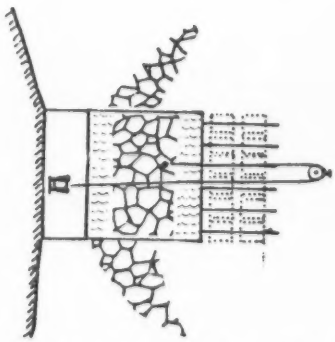
(B) CUTTING OF ICE AND SLOTS FOR TOWING CABLE.



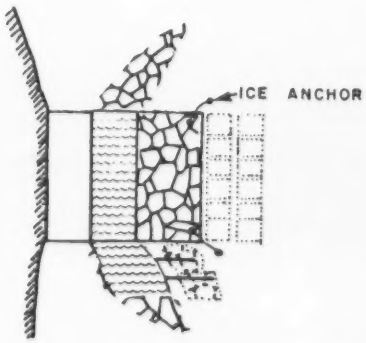
(C) TOWING BLOCKS UNDER ICE USING **BULLDOZER (BD) ON THE PIER.**



(D) BLOCKS UNDER ICE. CUT ROUGH SLAB FREE.



(E) TOW ROUGH SLAB INTO AREA VACATED IN (D). FASTEN WITH ICE ANCHOR.



(F) CUT ENTRY CHANNEL AND TOW BLOCKS UNDER. CUT EXIT CHANNEL (IF NECESSARY) PRIOR TO SHIP DEPARTURE

(NOT TO SCALE)

FIGURE 18
SEQUENTIAL PROCEDURE FOR REMOVING ROUGH ICE SECTION

4.2.3 Removal of Ice Near Open Water

In some situations, the harbour to be cleared of ice is located relatively close to an open water area which is accessible by ships. In these cases, it is expected that techniques developed for landfast ice can be adapted to produce large sheets of ice which can be towed out to open water by a ship. This concept was not tested in this study, however, it is suspected that the speed of the ice removal operations can be significantly increased by this method since a ship will be able to tow a relatively large ice sheet through the water.

Although field tests of this method have not yet been performed, it is tentatively proposed that the ice in harbours located near open water can be removed using one of the following methods:

1. A Ditch Witch with a wide cutting assembly can be used to cut a trench around several large ice sheets which can be towed into open water by a ship (see Figure 19a). The ice sheets along the sides of the area to be cleared can be cut at an angle to reduce possible jamming of these sheets against the sides of the surrounding ice.

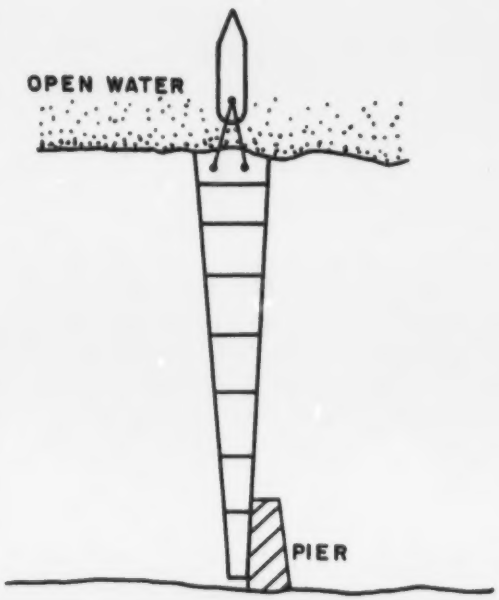
2. In cold weather when the refreezing of the trenches may present difficulties, the Ditch Witch can be used to cut two trenches along the sides of the ice sheets approximately 1 m apart (see Figure 19b). Chainsaws can then be used to cut the ice between the trenches into smaller chunks which can be pushed by hand under the surrounding ice to leave a narrow channel of open water which will reduce refreezing or jamming of the ice sheets.

3. In Arctic regions where rapid refreezing may be a significant problem, or in locations where the available towing power of the ship permits the use of larger ice sheets, it may be desirable to apply the techniques developed for landfast ice to create a wide channel of open water around these larger ice sheets (see Figure 19c). The small ice blocks can be towed along cable slots parallel to shore using a pulley with a bulldozer and winch on the pier, to form the wide channel around the ice sheets.

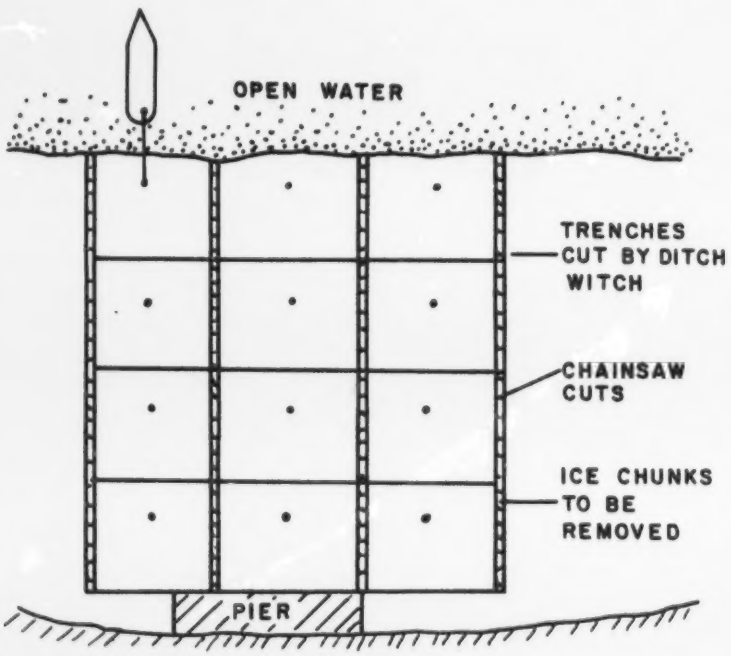
4.3 Projected Costs for Full Scale Operations

4.3.1 Cost Effectiveness Considerations

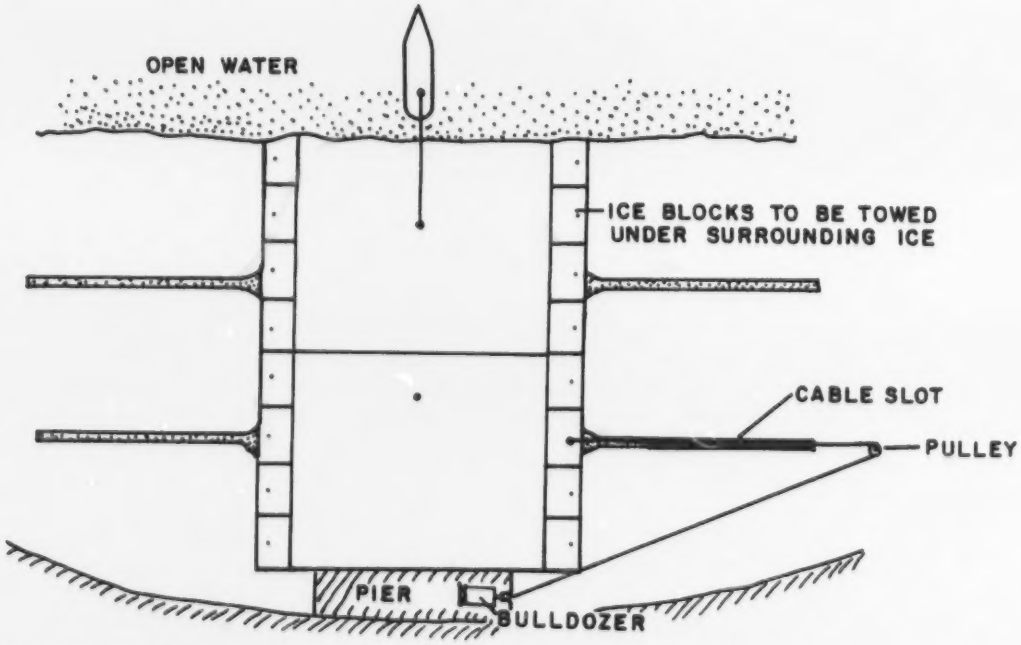
The large scale tests have demonstrated that the ice-block-under-ice towing concept is a technically feasible technique for creating large areas of open water adjacent to piers. However, the cost effectiveness of the method should be considered in assessing the feasibility of full scale operations to remove ice from ports and harbours.



(A) SINGLE TRENCH



(B) DOUBLE TRENCH



(C) TOWING ICE BLOCKS

FIGURE 19

METHODS FOR REMOVING ICE NEAR OPEN WATER

The overall cost of the ice removal operations should be weighed against the expenses incurred if the ice were not removed. For example, the ship time lost by cargo ships, the money lost from cargo handling operations and the time value of cargo not delivered under potential contracts plus insurance and related services should be considered. However, it is difficult to accurately predict these costs for all harbours in general, or even for a specific harbour in particular.

Similarly, it is difficult to compare the costs of the ice removal operations with the costs of icebreakers or mechanical cutting with chainsaws to weaken the ice adjacent to a pier. If the ice is broken or cut, but not removed, the cost of the additional time and fuel needed to berth cargo ships in the ice and the potential for damage to hull, machinery, propellers and rudder stock should be considered. In the case of ports and harbours in the Arctic, the costs of ship time, personnel, fuel and supplies associated with using an icebreaker to break up the ice adjacent to a pier would be distributed among the number of similar harbours to be serviced in the same area and would depend on the total distance to be travelled by the icebreaker. It is difficult to quantify and generalize these costs for comparison purposes.

4.3.2 Cost Estimates for Operations in Southern Canada

However, the large scale tests of the ice-block-under-ice concept can be used to estimate the cost of the ice removal operations per unit area of ice cleared, if it is assumed that the typical costs for most locations in Southern Canada are similar to those found in Ontario during the large scale tests. These cost estimates will be useful in any future evaluation of this method for specific application at a particular harbour. Since much of the time spent in the large scale testing was used in evaluating towing equipment and developing techniques for the application of the procedures on a large scale, the rate of ice removal is expected to increase during the full scale operations. The estimated total cost of equipment, personnel, supplies and services is computed for a specified area to be cleared and divided by the total area of ice removed to obtain a unit cost per square meter of ice removed. This unit cost may be useful in estimating the expense of clearing ice from a specific harbour location using this method, or in comparing the economic benefits of this method with other techniques such as air bubbler systems. These projected costs would be applicable to situations where smooth level ice is present, such as in harbours which are normally not in operation during the winter months, but require ice removal in the spring to begin operations at an earlier date.

For harbours which remain open throughout the winter, the removal of rough ice sections produced by the refreezing of ice broken by ships will involve additional expenses compared with the case of smooth level ice. The additional unit cost is combined with the cost of removing landfast ice, to obtain the total unit cost per square meter of ice removed. The removal of ice from piers near open water by towing

large ice sheets with a ship may be more cost effective in some cases, depending on the particular configuration of the harbour and the size of the area to be cleared.

Cost estimates for harbours in Arctic locations are not considered, since the transportation costs and availability of equipment are expected to vary widely with location and should be determined on a site-specific basis for a particular application. Although most Arctic areas can be expected to have a bulldozer with a winch, the availability of a Ditch Witch in these areas is highly unlikely.

Transportation costs near the larger Arctic towns which are serviced by commercial airlines may be slightly higher than those in Southern Canada. However, many of the more isolated areas which are only accessible by surface vehicles in the winter may have relatively high transportation costs for heavy equipment. The costs of meals and accommodation for the field personnel are also expected to be higher than in Southern Canada.

The cost of removing ice from a harbour will vary depending on the size of the area to be cleared, the local rates for equipment rentals and the local cost of supplies and services. If it is assumed that the typical costs for most locations in Southern Canada are similar to those found in Ontario during the large scale tests, then the cost of clearing ice can be estimated in terms of cost per unit area of ice removed for three scenarios:

A. Landfast Ice;
B. Rough Ice Sections; and
C. Ice Near Open Water.

a. Scenario A: Landfast Ice

For the case of landfast ice, the projected costs of the full scale operations are determined by using the operational speeds and machinery costs from the large scale tests as a guide. It is expected that the suggested modifications to the equipment and techniques will produce a faster rate of ice removal and a resulting decrease in cost per unit area of ice removed. In preparing the cost estimates for full scale operations, it is assumed that the rate of cutting ice with the Ditch Witch is approximately 183 m/hr, while the ice cutting rate for the chainsaws is assumed to be 50 m/hr. It is assumed that the maneuvering, tilting and towing of the ice blocks will proceed at an average rate of 4 blocks per hour or 40 blocks per 10 hour day.

The unit cost is based on the assumption that a 50 by 200 m area of ice 60 cm thick is to be cleared to create an open water area of 10,000 sq. m. If the ice blocks are cut 5 by 8 m in size, an array of 250 blocks will be produced, 10 blocks wide by 25 blocks in length (see Figure 20). It will be assumed that 20 cable slots will be cut, with each slot 65 m long to accommodate the excess blocks to be stored. The total cost of removing ice from this area is estimated and

CUTTING BY DITCH WITCH : 26 x 50 m = 1300
20 x 65 m = 1300
2600 m

CUTTING BY CHAIN SAWS 10 x 200 m = 2000 m

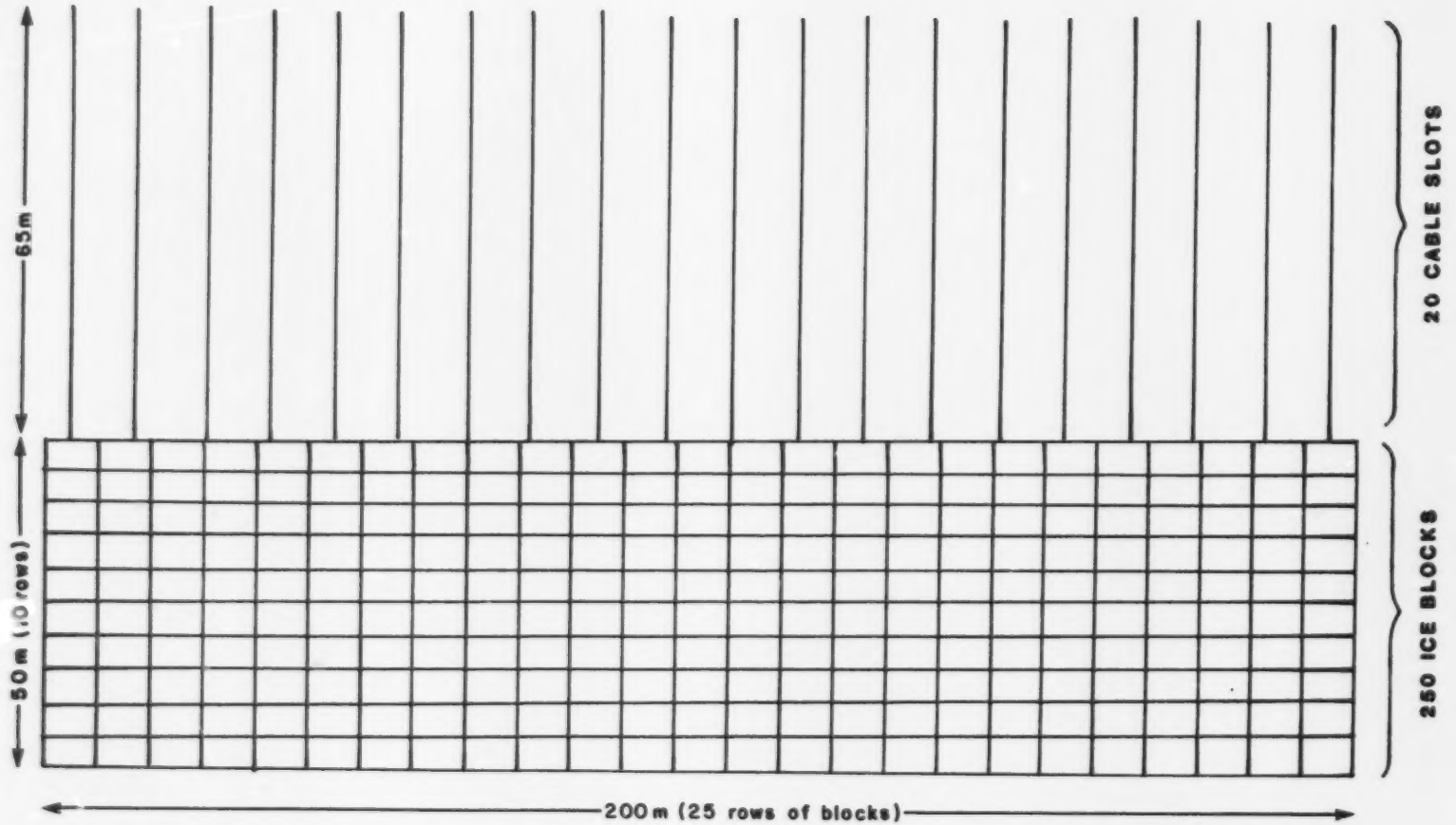


FIGURE 20
REMOVAL OF LANDFAST ICE FROM 50 BY 200m AREA

the corresponding unit cost is then obtained by dividing by the area of ice removed.

If the Ditch Witch is used to cut the sides of each row of blocks and the cable slots, the total distance of 2,600 m could be cut in a minimum of 14.2 hours. The leading edges of the ice blocks, which comprise a total distance of 2,000 m could be cut in a minimum of 40.0 hours, but this equipment should be available for the duration of the operations. The drilling of the ice anchor holes with an ice auger, electric drill and generator can be done quite rapidly with little effort, and can be carried out simultaneously with the chainsaw cutting process, but this equipment will also be needed throughout the entire operation. The cutting of trenches with the Ditch Witch can be performed independently and in advance of the chainsaw cutting procedures. The removal of the 250 ice blocks at the rate of 4 blocks per hour will take about 62.5 hours, and will determine the duration of the ice removal operations.

The total duration of 6.25 days is used to compute the total cost of the leased equipment, personnel, supplies and services (on a prorated basis) for clearing the 50 by 200 m area. The cost estimate is presented in Table 4. The unit cost of ice removal is determined by dividing the total cost of about $15,300 by the total open water area of 10,000 sq m. The projected unit cost is expected to be approximately $1.53 per sq m for harbours located in Southern Canada. This figure should be considered to be only an order of magnitude estimate, since the costs may vary slightly with location, particularly in the more isolated regions.

b. Scenario B: Rough Ice Sections

The presence of rough ice sections adjacent to the pier and in the entry and exit channels will increase the cost of the ice removal operations. The increased costs will result from the cutting and towing of the rough ice slabs and the installation of ice anchors to hold the floating slabs in place.

The additional expenses associated with the removal of rough ice sections have been estimated in terms of cost per unit area of rough ice for harbours located in Southern Canada. The projected costs for removing rough ice sections should be added to the cost estimates for landfast ice in situations where rough ice is present in the harbour to be cleared.

Although tests have not been conducted with rough ice, it is assumed that the rate of cutting rough ice with the Ditch Witch is similar to that for smooth ice. The assumption is made that a 50 by 200 m section of rough ice is to be cut and towed into the open water area created by the ice-block-under-ice technique. If it is assumed that 10 slabs of rough ice, each 25 by 40 m in size, can be easily towed by the bulldozer and winch, then a total distance of about 500 m (six trenches 50 m long and a single trench 200 m long, neglecting the

TABLE 4

ESTIMATE OF COSTS ASSOCIATED WITH REMOVAL OF LANDFAST ICE FROM A 50 BY 200 m AREA

Estimated Duration of Operations = 6.25 days

Leased Equipment	Rate	Cost
1 Ditch Witch (2,600 m - 183 m/hr = 14.2 hrs minimum)	$175/day	$ 1,093.75
1 bulldozer, with operator (250 blocks - 4 blocks/hr = 62.5 hrs)	440/day	2,750.00
2 chainsaws (2,000 m - 50 m/hr = 40.0 hrs minimum	70/day	437.50
1 ice auger	25/day	156.25
1 electric generator	25/day	156.25
1 snowmobile	35/day	218.75
		4,812.50
Personnel		
1 Field supervisor	290/day	1,812.50
4 Field personnel (each $250/day)	1,000/day	6,250.00
		8,062.50
Supplies		
Gasoline (45 litres/day)	20/day	125.00
Chainsaw oil (2 litres/day)	5/day	31.25
		156.25
Services		
Accommodation (5 people, each $20/day)	100/day	625.00
Meals (5 people, each $34/day)	170/day	1,062.50
Transportation	95/day	593.75
		2,281.25
TOTAL COST		$15,312.50

TOTAL AREA CLEARED - 10,000 sq. m.

UNIT COST = $15,312.50 ÷ 10,000 sq. m = $1.53/sq. m.

open water edge and the edge along the pier which is assumed to be free due to tidal activity) must be cut with the Ditch Witch. If the trenching progresses at a rate of 183 m/hr, this task should be completed in about 2.7 hours. If the rough slabs are then towed and secured in place by installing ice anchors at an assumed rate of 2 slabs per hour, then these procedures should be completed in an additional 5 hours. The total duration of the operations to remove rough ice is approximately 0.75 days.

The additional cost of the leased equipment, personnel, supplies and services (on a prorated basis) is shown in Table 5. The unit cost is determined by dividing the additional cost of about $1,300 by the total open water area of 10,000 sq m. The additional unit cost of $0.13 per sq m for removing rough ice from harbours in Southern Canada is then combined with the cost for landfast ice to obtain a total unit cost of approximately $1.66 per sq m. This cost estimate is not considered to be applicable to harbours in Arctic locations, and should be considered to be only an order of magnitude estimate for operations in Southern Canada, until future testing of the cutting and towing of rough ice sections can provide more accurate estimates of the cutting speed, the size of the rough slabs and the time required for towing and securing the slabs.

c. Scenario C: Ice Near Open Water

The removal of ice from piers near open water may be more cost effective in some cases if a ship is used to tow large ice sheets out to open water. Although this concept was not tested in this study, it is suggested that large areas can be rapidly cleared in these situations, if the configuration of the harbour is suitable. The expenses related to the cutting operations are expected to be reduced, since the area will be divided into a small number of large sheets which will result in a decreased cutting distance.

The projected costs of removing ice near open water using ships have been estimated in terms of cost per unit area of ice removed for harbours located in Southern Canada. Cost estimates are presented in this section for only two of the three methods previously described. The costs for the third method are not included, since this technique was suggested primarily for use in Arctic regions rather than in Southern Canada.

Since the use of ships permits the towing of much larger ice sheets, the assumption will be made that an open water area 50 by 2,000 m is to be cleared. Tests of the ice sheet towing capabilities of ships have not been included in this study. However, if it is assumed that 10 ice sheets, each 50 by 200 m in size can be easily towed by a typical tugboat, then a total distance of about 4,300 m (a trench 2,000 m and 1,800 m long, and 10 trenches 50 m long, neglecting the open water and pier edges) must be cut with the Ditch Witch for the single trench method shown in Figure 21a. If the trench is cut at a rate of 183 m/hr, the ice sheets could be cut in approximately 23.5 hours.

TABLE 5

ESTIMATE OF ADDITIONAL COSTS ASSOCIATED WITH
REMOVAL OF ROUGH ICE SECTIONS

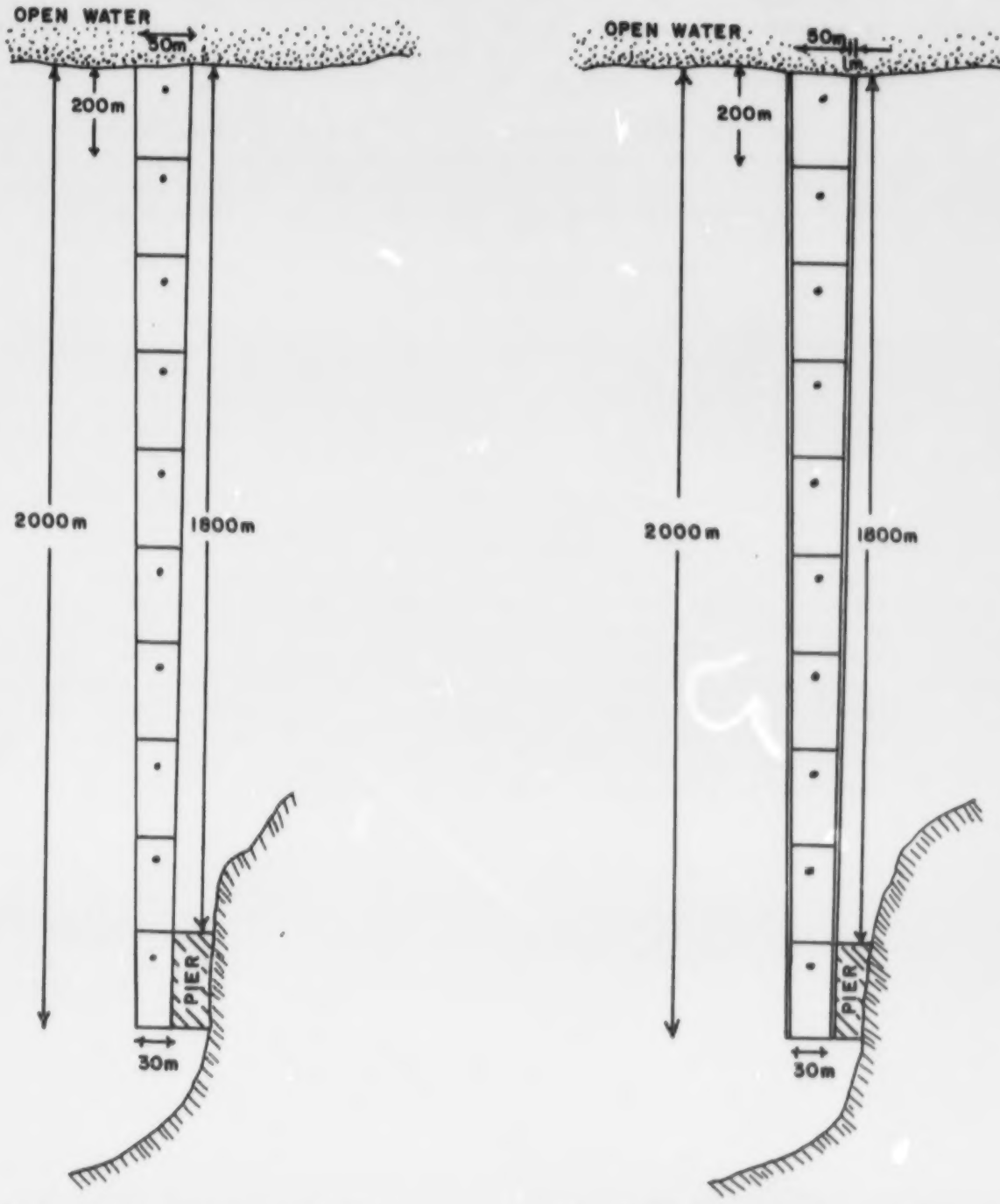
Estimated Duration of Additional Operations = 0.75 days

Leased Equipment	Rate	Cost
1 Ditch Witch (500 m - 183 m/hr = 2.7 hrs minimum)	$175/day	$ 131.25
1 bulldozer, with operator (10 slabs - 2 slabs/hr = 5 hrs)	440/day	330.00
1 ice auger	25/day	18.75
1 electric generator	25/day	18.75
1 snowmobile	35/day	26.25
		525.00
Personnel		
1 Field supervisor	290/day	217.50
4 Field personnel (each $250/day)	500/day	375.00
		592.50
Supplies		
Gasoline (45 litres/day)	20/day	15.00
		15.00
Services		
Accommodation (3 people, each $20/day)	60/day	45.00
Meals (3 people, each $34/day)	102/day	76.50
Transportation	95/day	71.25
		192.75
ADDITIONAL COST FOR ROUGH ICE		1,325.25
BASIC COST FOR LANDFAST ICE ONLY		15,312.50
TOTAL COST		$16,637.75

TOTAL AREA CLEARED - 10,000 sq. m.

ADDITIONAL UNIT COST
FOR ROUGH ICE ONLY - $1,325.25 ÷ 10,000 sq. m. = $0.13/sq. m.
BASIC UNIT COST FOR LANDFAST ICE ONLY - 1.53/sq. m.

TOTAL UNIT COST FOR ROUGH ICE $1.66/sq. m.



(A) SINGLE TRENCH METHOD

(B) DOUBLE TRENCH METHOD

FIGURE 21

REMOVAL OF ICE NEAR OPEN WATER

The installation of ice anchors and towing of the ice sheets by a ship is expected to proceed rapidly and be carried out simultaneously with the cutting process. The total duration of the ice removal operation is approximately 2.35 days for the single trench method.

For the double trench method shown in Figure 21b a total distance of 8,100 m (two trenches 2,000 m long, 2 trenches 1,800 m long and 10 trenches 50 m long, neglecting the open water and pier edges) must be cut with the Ditch Witch. At a cutting speed of 183 m/hr, the ice sheets could be cut in 44.3 hrs. The 1 m space between the trenches must then be cut into smaller chunks which can be pushed under the surrounding ice. If 1 by 2 m rectangular pieces are cut, the total distance to be cut with the chainsaws is about 1,900 m (1,000 cuts of 1 m and 900 cuts of 1 m). If the cutting progresses at the rate of 50 m/hr and the submerging of the ice chunks is carried out simultaneously, then this operation should take 76.0 hrs. The total duration would then be approximately 7.60 days for the double trench method.

The total cost of the leased equipment, personnel, supplies and services (on a prorated basis) is shown in Table 6 for both methods. The single trench method is estimated to have a total cost of about $7,800 while the total cost of the double trench method is about $30,500. Since the total area cleared is 100,000 sq m, the unit costs are $0.08/sq m and $0.30/sq m, respectively. These cost estimates are not considered to be applicable to harbours in Arctic locations, and should be considered to be only order of magnitude estimates for operations in Southern Canada, until future testing of these concepts can provide more accurate estimates of the speed of cutting and submerging the ice chunks, the size of the ice sheets and the time required for towing the ice sheets with a ship.

TABLE 6

ESTIMATE OF COSTS ASSOCIATED WITH REMOVAL OF ICE
NEAR OPEN WATER

a. Single Trench Method

Estimated Duration of Operations = 2.35 days

Leased Equipment	Rate	Cost
1 ship	$2,000/day	$ 4,700.00
1 Ditch Witch (4,300 m - 183 m/hr = 23.5 hrs)	$175/day	411.25
1 ice auger	25/day	58.75
1 electric generator	25/day	58.75
1 snowmobile	35/day	82.25
		5,311.00
Personnel		
1 Field supervisor	290/day	681.50
4 Field personnel (each $250/day)	500/day	1,175.00
		1,856.50
Supplies		
Gasoline (45 litres/day)	20/day	47.00
		47.00
Services		
Accommodation (3 people, each $20/day)	60/day	141.00
Meals (3 people, each $34/day)	102/day	239.70
Transportation	95/day	223.25
		603.95
TOTAL COST		$ 7,818.45

TOTAL AREA CLEARED - 100,000 sq. m.

UNIT COST FOR SINGLE TRENCH METHOD - $7,818.45 ÷ 100,000 sq. m. = $0.08/sq. m.

TABLE 6 (Continued)

ESTIMATE OF COSTS ASSOCIATED WITH REMOVAL OF ICE
NEAR OPEN WATER

b. Double Trench Method

Estimated Duration of Operations = 7.60 days

Leased Equipment	Rate	Cost
1 ship	$2,000/day	$15,200.00
1 Ditch Witch (8,100 m - 183 m/hr = 44.3 hrs minimum)	$175/day	1,330.00
2 chainsaws (3,800 m - 50 m/hr = 76.0 hrs minimum)	70/day	532.00
1 ice auger	25/day	190.00
1 electric generator	25/day	190.00
1 snowmobile	35/day	266.00
		17,708.00
Personnel		
1 Field supervisor	290/day	2,204.00
4 Field personnel (each $250/day)	1,000/day	7,600.00
		9,804.00
Supplies		
Gasoline (45 litres/day)	20/day	152.00
Chainsaw oil (2 litres/day)	5/day	38.00
		190.00
Services		
Accommodation (5 people, each $20/day)	100/day	760.00
Meals (5 people, each $34/day)	170/day	1,292.00
Transportation	95/day	722.00
		2,774.00
TOTAL COST		$30,476.00

TOTAL AREA CLEARED - 100,000 sq. m.

UNIT COST FOR DOUBLE TRENCH METHOD - $30,476.00 ÷ 100,000 sq. m. = $0.30/sq. m.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The feasibility study of the ice break and removal techniques indicates that the following conclusions can be drawn:

1. The towing of an ice block under the surrounding ice to expose an area of open water has been shown to be technically feasible with commercially available equipment.

2. The application of the ice-block-under-ice concept on a large scale has been demonstrated to be a technically feasible method for creating large open water areas in an ice surface.

3. Specialized equipment for rapidly towing ice blocks under the surrounding ice can be fabricated at low cost for use in full scale operations to clear ice from harbours.

4. Modifications of the ice removal techniques can be used in full scale ice removal operations to deal with rough ice sections adjacent to piers and ice near open water areas.

5. Estimates of the cost per unit area of ice removed in the large scale tests can be used as a guide in projecting the cost of full scale operations at various harbour locations in Southern Canada, but not in the Arctic regions.

6. Additional testing of thicker ice in the colder environment of the Arctic is necessary to determine the feasibility of the ice-block-under-ice concept in these conditions.

5.2 Recommendations

Based on the results of this study, it is recommended that further research should be carried out on the following aspects of the ice break and removal techniques:

1. The proposed modifications of equipment for the full scale operations should be carried out and tested.

2. The procedures for full scale ice removal to provide access to piers surrounded by landfast ice should be tested at a harbour location in Southern Canada.

3. Large-scale testing of the proposed procedures for dealing with rough ice sections and ice near open water should be

performed to evaluate the feasiblity of these methods.

4. The full scale operations for removing rough ice sections and ice near open water should be tested at a harbour location in Southern Canada, if these methods are shown to be feasible.

5. Small-scale and large-scale testing of the ice-block-under-ice concept should be conducted using the thicker ice and the colder environment of the Arctic.

6. The procedures for full scale ice removal from harbours should be tested at a harbour location in the Arctic, if these methods are shown to be feasible in this environment.

REFERENCES

1. "Ice Saw cuts trench quickly, speeds lake line installation", 1975, Oil/Gas Pipelining Handbook, 3rd edition, ed. Dean Hale, Energy Communications Inc. (Petroleum Engineer Publishing Co.), pp.340-341.

APPENDIX A - Photo Series Record of Tests - Plates 1 through 25

A photo series record of all tests is presented in this appendix. The photograph shown in Plate 1 was taken during the small scale tests at Anderson Lake, Nova Scotia, while small scale testing on the Miramichi River, New Brunswick is shown in Plates 2 through 6. The equipment used in the large scale testing is illustrated in Plates 7 through 16, and the ice operations during the large scale tests are shown in Plates 17 through 25.

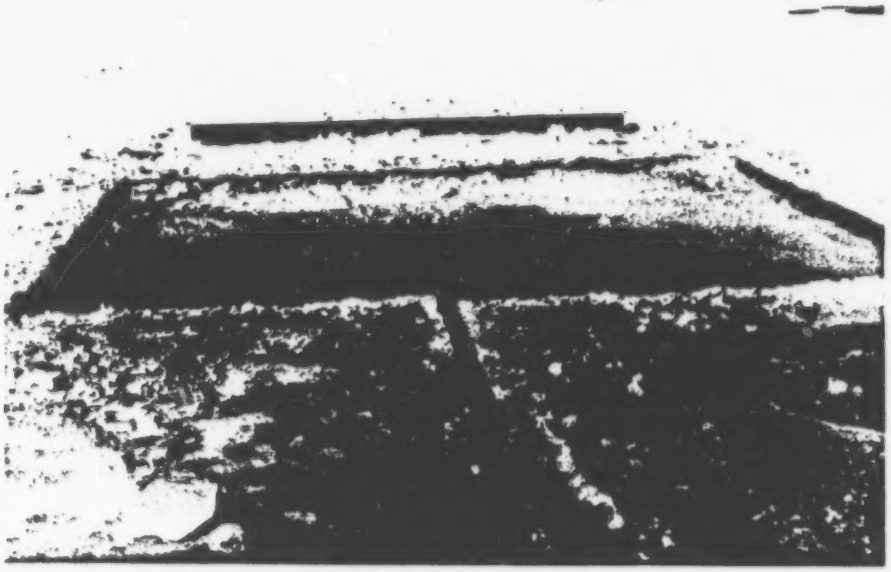


PLATE 1
SUBMERGING ICE BLOCK IN ANDERSON LAKE

PLATE 2
ICE OPERATIONS ON THE MIRIMICHI RIVER

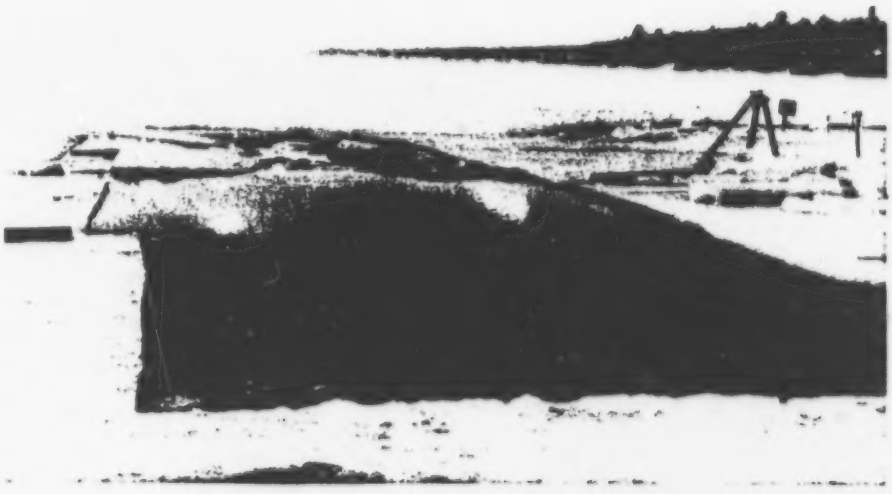


PLATE 3
OPEN WATER AREA PRODUCED AFTER SUBMERGING TWO ICE BLOCKS

PLATE 4
ALTERNATIVE TECHNIQUE USING BACKHOE

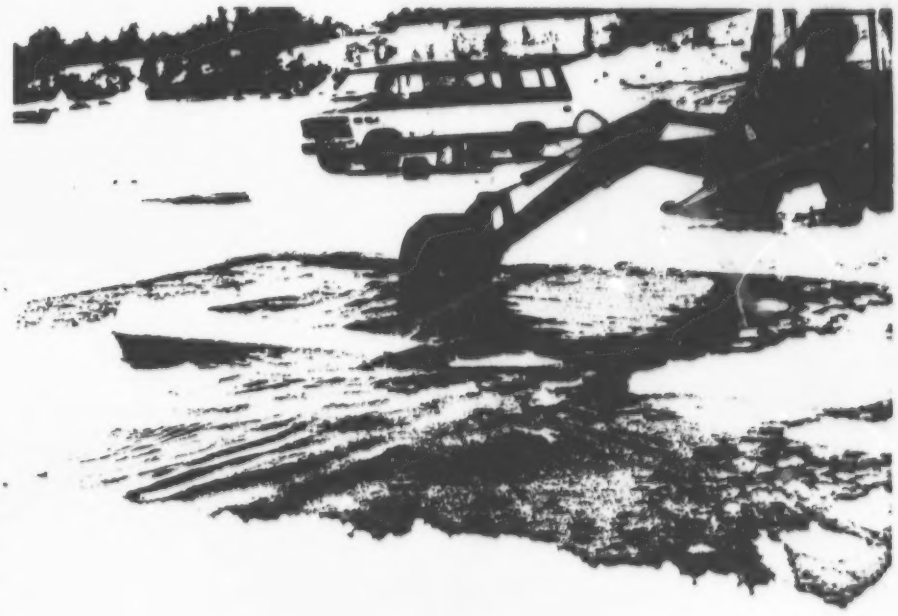


PLATE 5

BACKHOE SUBMERGING BROKEN ICE PIECES

PLATE 6

AREA CLEARED BY BACKHOE

PLATE 7
MODIFIED TRIPOD

PLATE 8
TRIPOD HEAD WHICH SUPPORTS TOWING CABLE

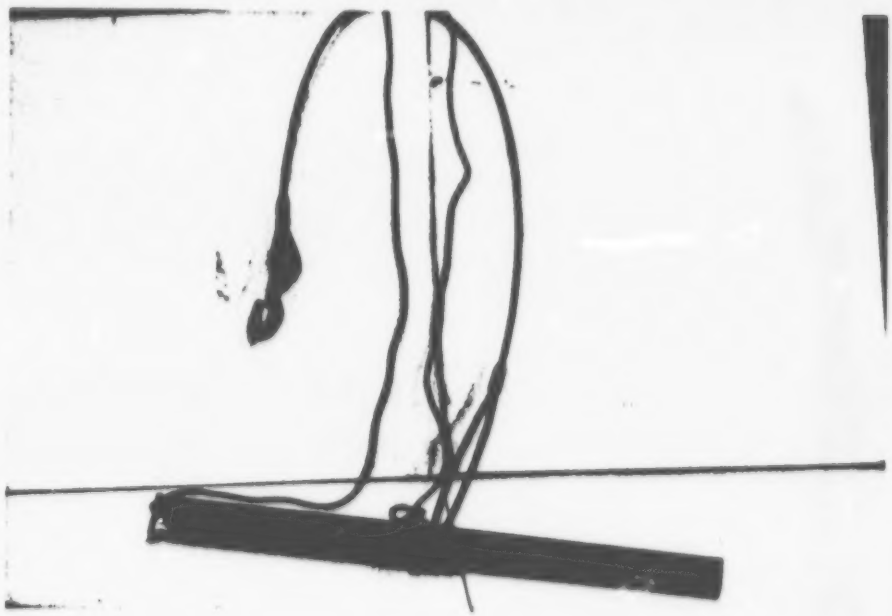


PLATE 9
ICE ANCHOR

PLATE 10
PRY BAR

PLATE 11
PRY BAR

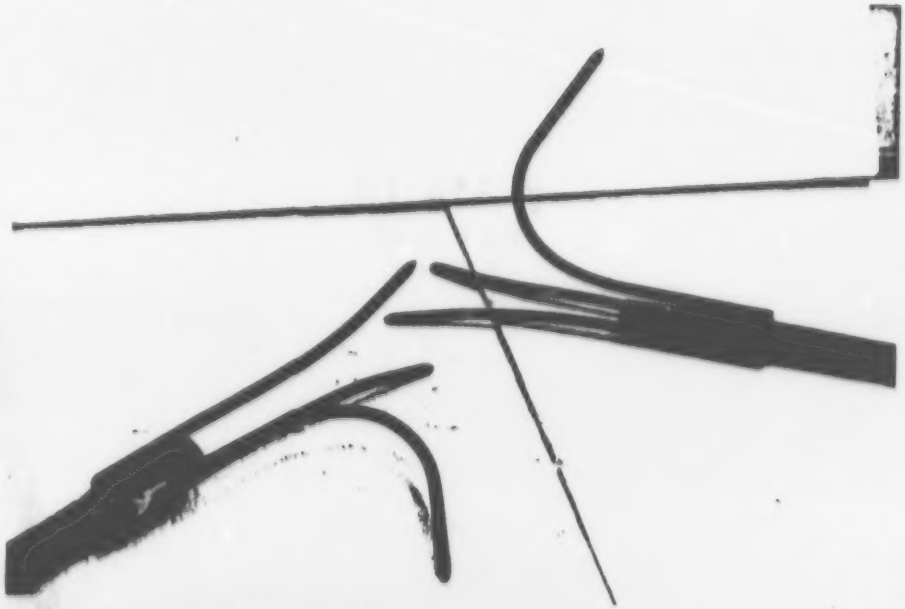


PLATE 12
PIKE POLE FOR MANEUVERING ICE PIECES

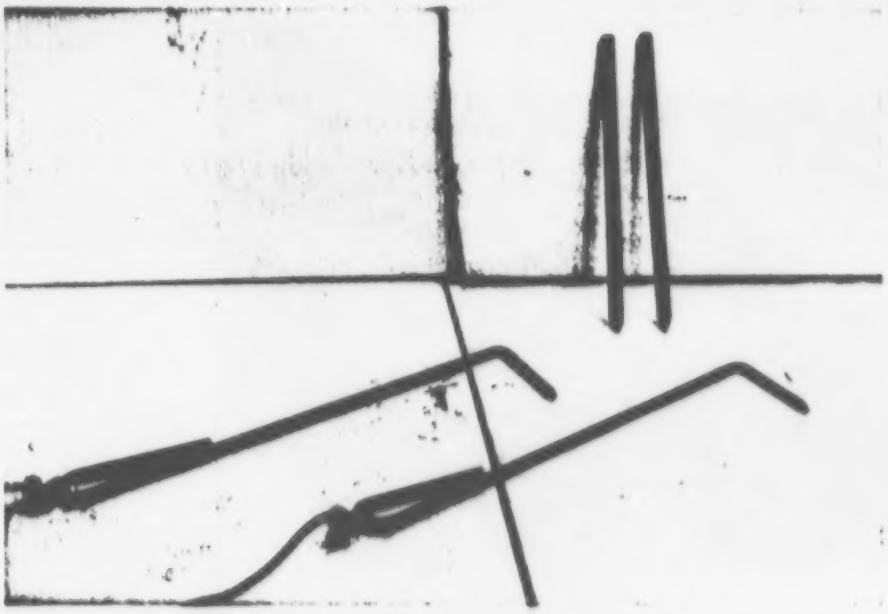


PLATE 13
HOOKS AND STAKE TO HOLD AND POSITION ICE BLOCKS

PLATE 14
CLEARING SNOW WITH DITCH WITCH

PLATE 15
DITCH WITCH CUTTING ICE

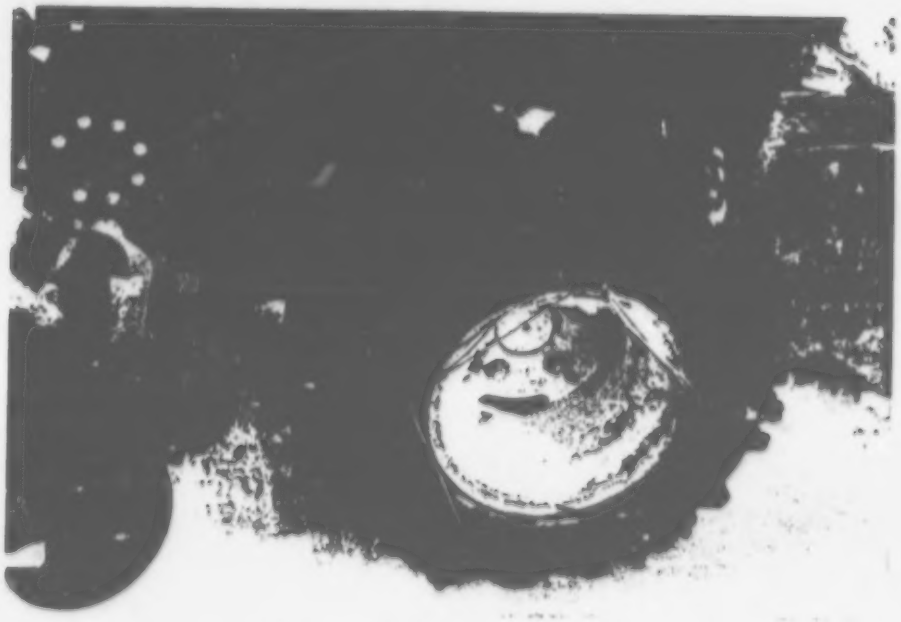


PLATE 16
TIRE CHAINS

PLATE 17
CUTTING CABLE SLOT

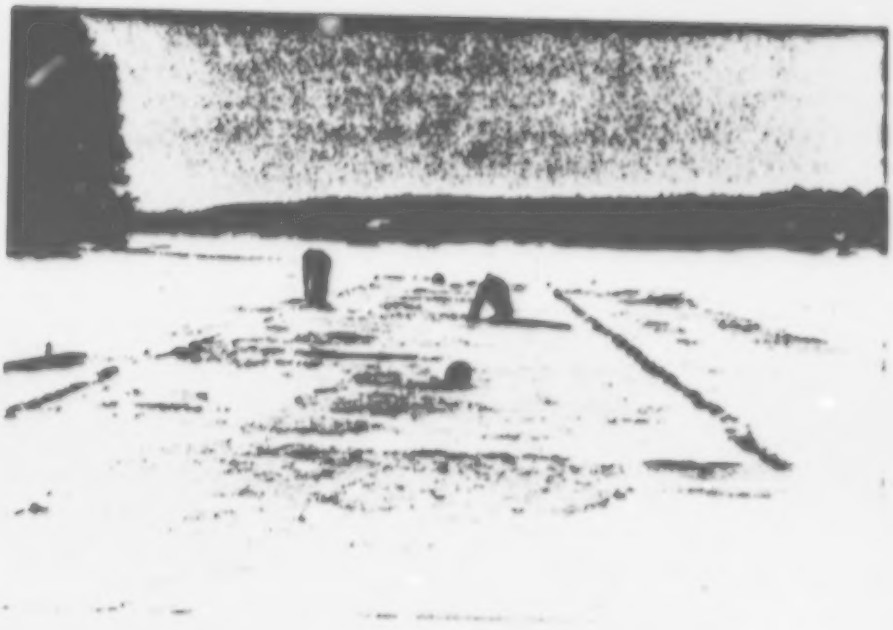


PLATE 18
CUTTING ICE WITH CHAINSAWS

PLATE 19
CABLE SLOT TOWARDS SHORE

PLATE 20
CRACKING OF ICE ON FIRST ROW OF BLOCKS

PLATE 21
SUBMERGING ICE BLOCK WITH TRIPOD

PLATE 22
REMOVAL OF TRIPOD

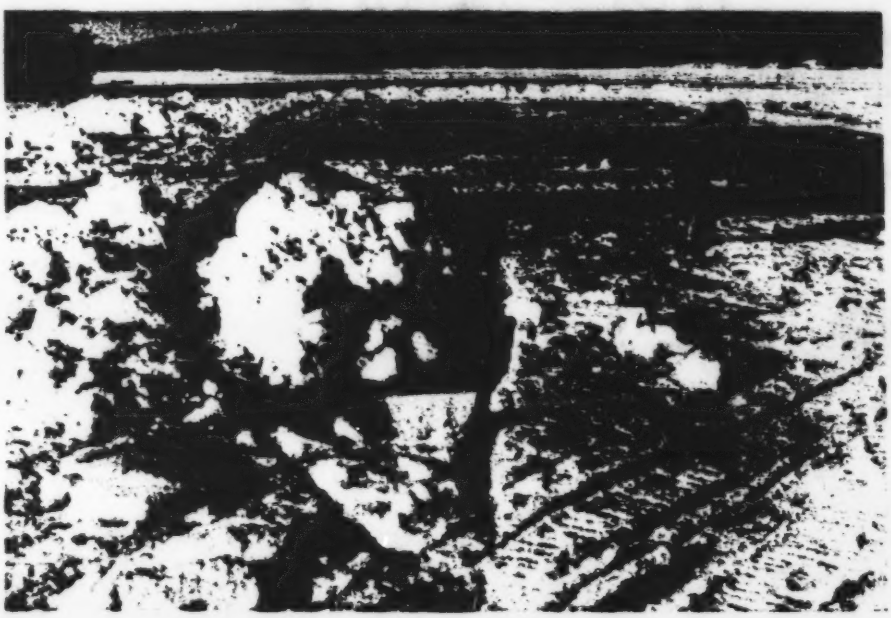


PLATE 23
SNOW PILED ON CRACKED ICE CHUNK USED TO SUBMERGE REMAINING ICE BLOCKS

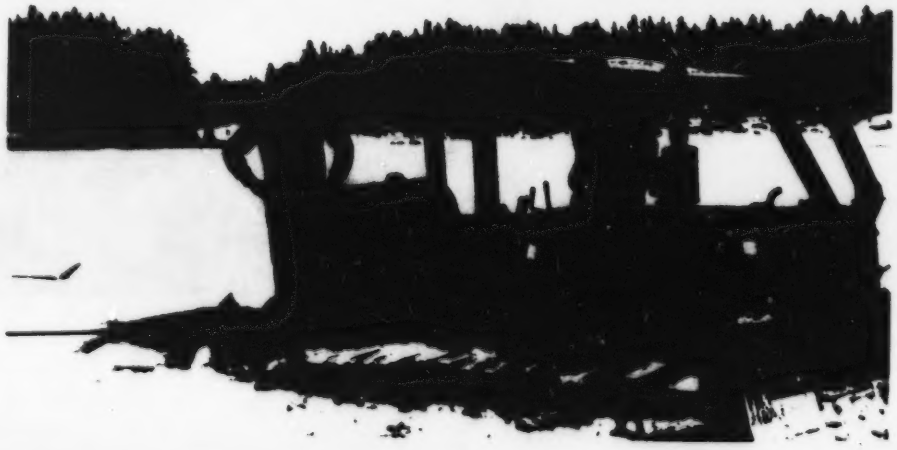


PLATE 24
D-6 BULLDOZER USED FOR TOWING

PLATE 25

AREA CLEARED DURING LARGE SCALE TEST

APPENDIX B - Video Tape Sequence Plates 26 through 43

The following plates were taken from a video tape sequence of the ice clearing operations. Plates 26 to 39 demonstrate the technique using the tripod, while Plates 40 to 43 illustrate the faster method using a straight pull to tilt the ice block.

PLATE 26
INSTALL TRIPOD AND ICE ANCHOR

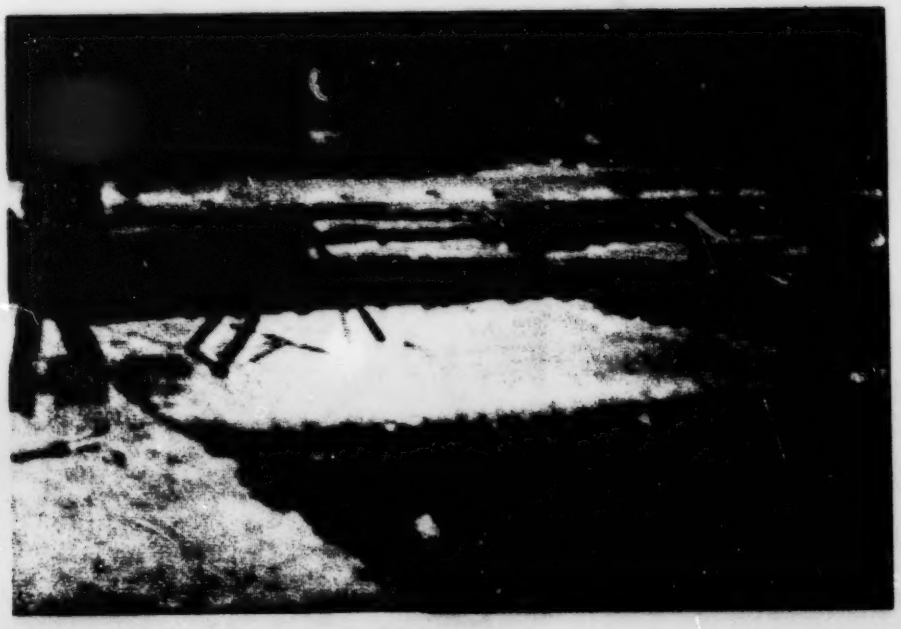


PLATE 27
APPLY TENSION TO CABLE

PLATE 28
BLOCK BEGINNING TO SUBMERGE

PLATE 29
BLOCK SUBMERGED

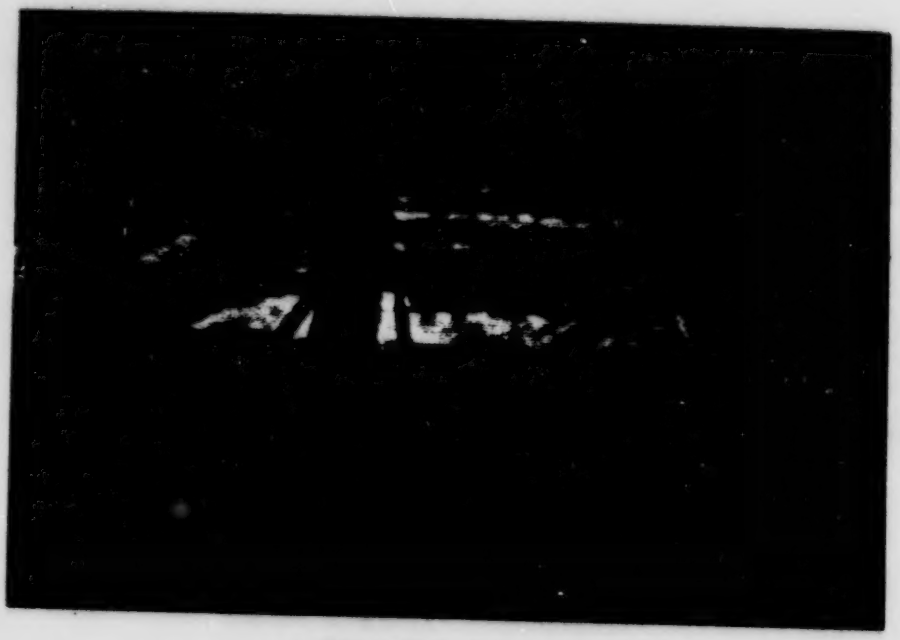


PLATE 30
SLACKEN TOWING CABLE

PLATE 31
REMOVE TRIPOD

PLATE 32
TRIPOD REMOVED

PLATE 33
INSERT ICE GUIDE

PLATE 34
APPLY TENSION TO TOWING CABLE

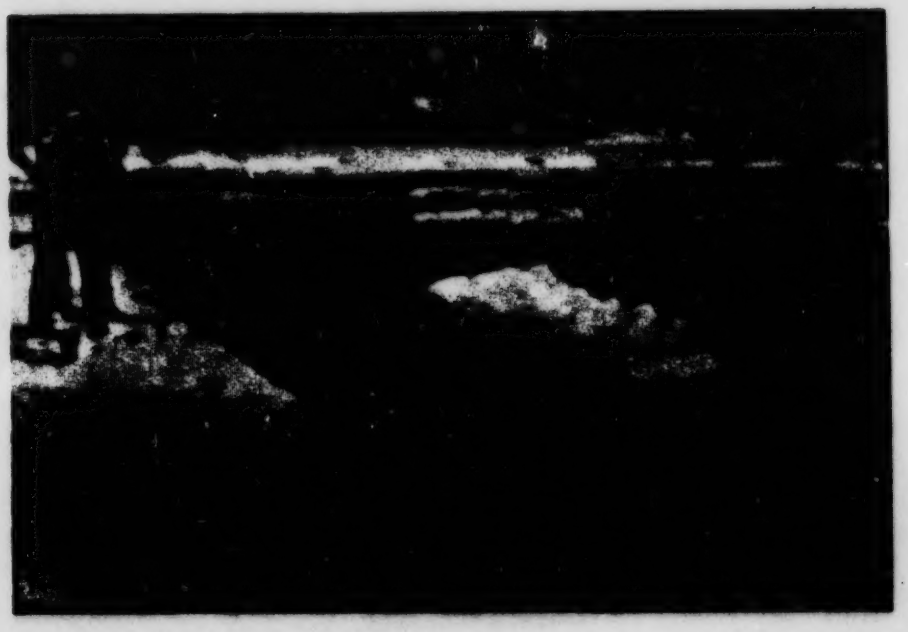


PLATE 35
BLOCK BEGINS TO MOVE UNDER SURROUNDING ICE

PLATE 36
BLOCK MAY ROTATE SLIGHTLY AT THIS POINT

PLATE 37
BLOCK HAS STRAIGHTENED OUT

PLATE 38
BLOCK COMPLETELY SUBMERGED

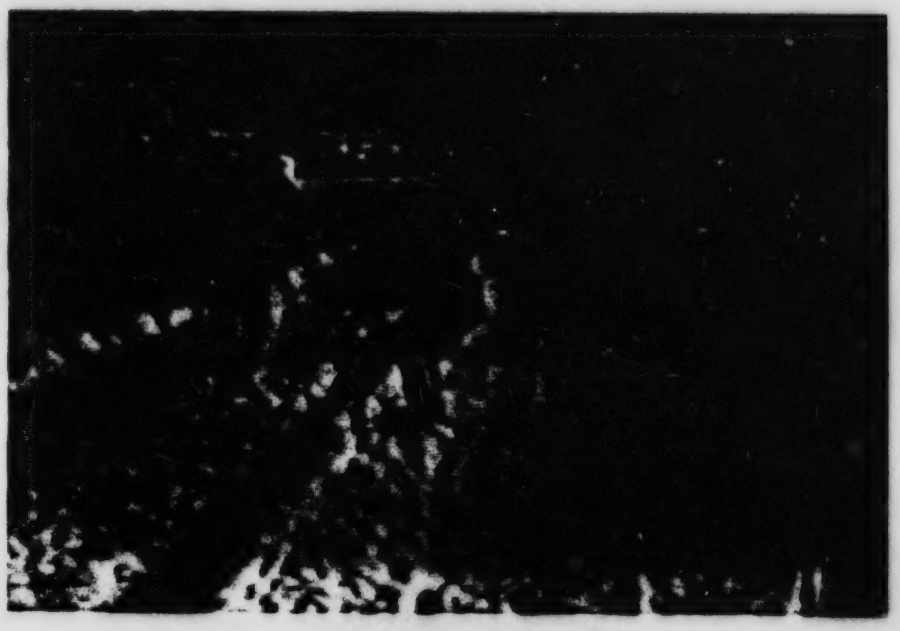


PLATE 39
BLOCK TOWED TO POSITION, THEN
ICE ANCHOR AND GUIDE REMOVED

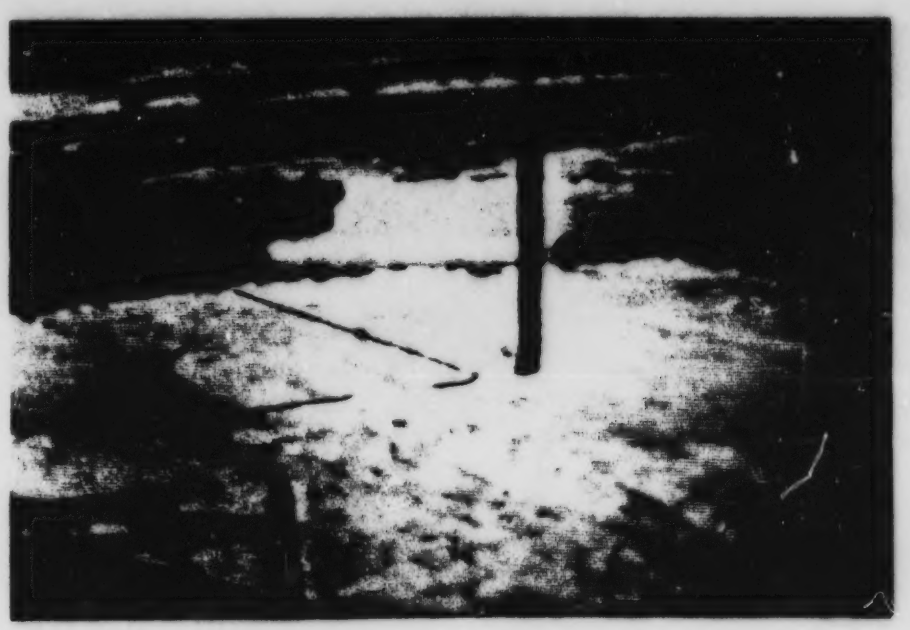


PLATE 40
REMOVAL TECHNIQUE WITHOUT USING TRIPOD

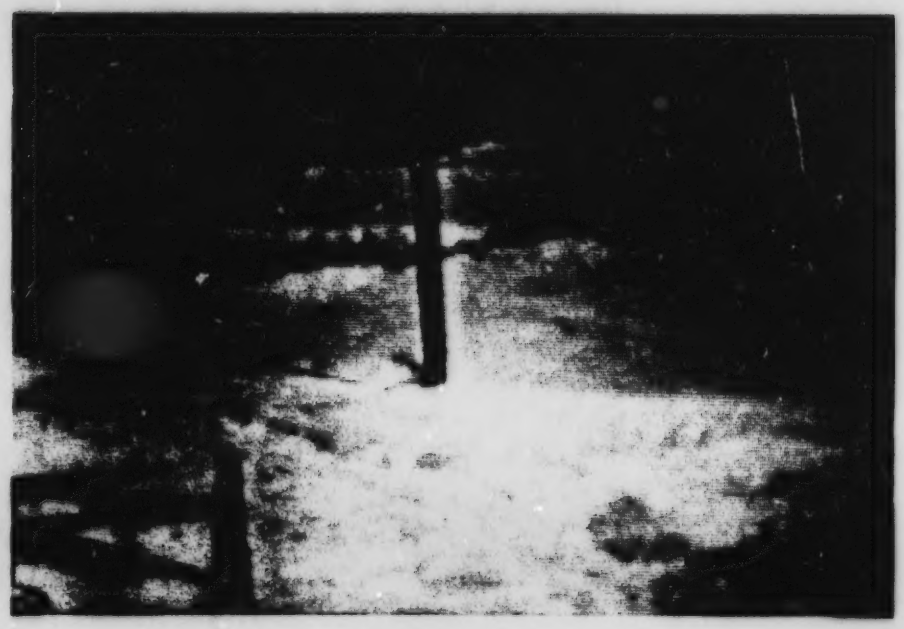


PLATE 41
BLOCK BEGINS TO TILT

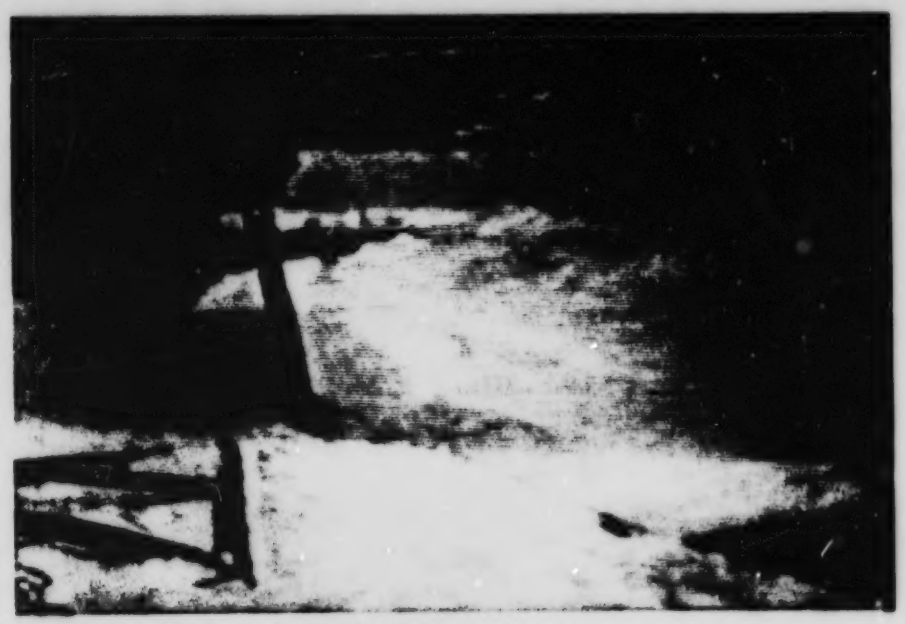


PLATE 42
BLOCK SUBMERGING

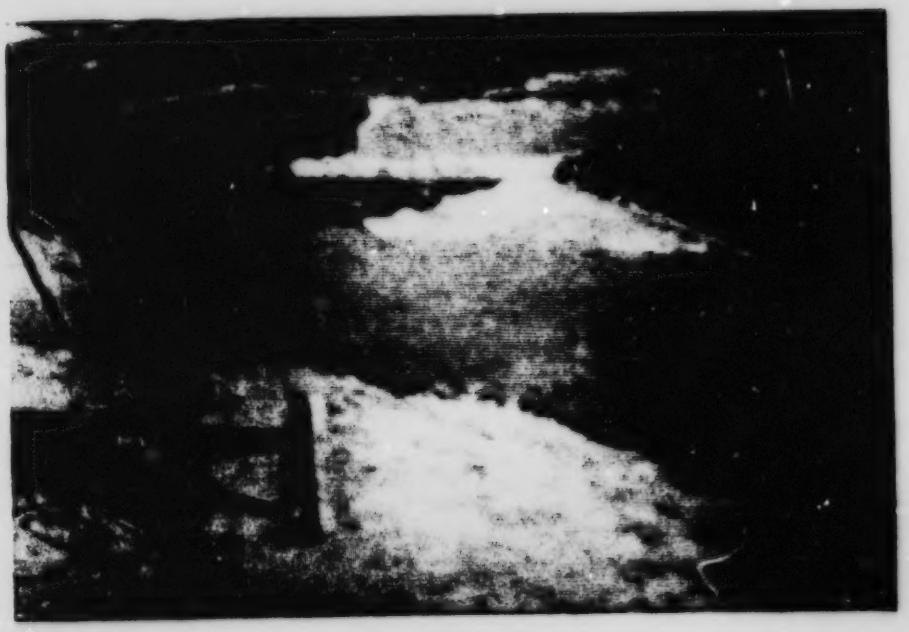


PLATE 43
BLOCK SUBMERGED